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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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THESIS

COMBAT MODELING FOR
COMMAND, CONTROL, AND COMMUNICATIONS:
A PRIMER

by

Joel Thomas Swanson
and
John Herbert Gibson

March, 1990

Thesis Advisor: Wayne P. Hughes, Jr
CAPT, USN (Ret)

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Combat Modeling for Command, Control, and Communications: A Primer

by

Joel T. Swanson
Lieutenant, United States Navy
B.S., Colorado School of Mines, 1983

and

John H. Gibson
Captain, United States Air Force
B.A., Point Loma College, 1977

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(Command, Control, and Communications)

from the
NAVAL POSTGRADUATE SCHOOL
MARCH 1990

Author: Joel T. Swanson
Joel T. Swanson

Author: John H. Gibson
John H. Gibson

Approved by: Wayne P. Hughes, Jr.
Wayne P. Hughes, Jr.

Dan C. Boger
Dan C. Boger

Carl R. Jones
Carl R. Jones, Chairman
Command, Control, and Comunications Academic Group

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Unlimited Distribution, Approved for Public Release
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL (If applicable) 39	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
COMBAT MODELING FOR COMMAND, CONTROL, AND COMMUNICATIONS: A PRIMER

12. PERSONAL AUTHOR(S)
Swanson, Joel T. Gibson, John H.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Master's Thesis	FROM ____ TO ____	March 1990	127

16. SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Command and Control, Measures of Effectiveness, Lanchester Equations, Pulsed Power model, QJM, Chaos Theory.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis is a primer for a combat modeling course for Joint Command, Control, and Communications (C3) students at the Naval Postgraduate School. It provides the students with a single document which ties together the concepts of several modeling experts pertinent to C3.

The thesis examines various aspects of combat models and introduces some of their functions, applications, and results. Areas included in the primer are: combat theory and definitions for command and control reflected in that theory; modeling techniques; measures of effectiveness; history of naval modeling; and a survey of current modeling efforts, such as simulation, Chaos Theory, and Decision Support Aids.

The thesis introduces basic concepts and identifies readings from which those concepts were extracted. It does not teach students to develop combat models, though it gives insight into how the application affects proper model selection.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Wayne P. Hughes, Jr., CAPT, USN (Ret)	22b. TELEPHONE (Include Area Code) (408)646-2484 22c. OFFICE SYMBOL OR/Hl

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

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The thesis examines various aspects of combat models and introduces some of their functions, applications, and results. Areas included in the primer are: combat theory and definitions for command and control reflected in that theory; modeling techniques; measures of effectiveness; attrition models, particularly Lanchester type equations; history of naval modeling; and a survey of current modeling efforts, such as simulation, Chaos Theory, and Decision Support Aids.

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ACKNOWLEDGEMENTS

The authors are grateful for the opportunity to have studied under the leadership of Wayne P. Hughes, CAPT, USN (Ret). It is a rare privilege to have been insturucted by one so prominent and well respected in military analysis. His effort and guidance were instrumental in the accomplishment of this thesis.

Additionally, the authors wish to express their thanks to Dr. Dan Boger and Dr. Carl Jones for providing the opportunity to contribute to the continuing evolution of the Joint Command, Control, and Communications Curriculum.

I. INTRODUCTION

This thesis is designed to be a primer for CC3001, a combat modeling course at the Naval Postgraduate School for students in the Joint C3 curriculum. It provides the students with a single document that ties together the concepts which the course is designed to teach.

The purpose of this course is to give C3 students a background in combat modeling and analysis. Since the end result of a combat model is, in general terms, a "decision aid" for a commander who needs to make some kind of decision affecting the troops under his control, it is important for the study of C3 to look at how these models are constructed and how the results are utilized.

The course treats analysis of operations and battles, not the modeling of the C2 process; it is about making better decisions, rather than the decision process.

This course outline is divided into nine chapters which deal with separate issues of combat modeling. Chapter II develops a theory of combat to give students a common reference for dealing with combat terminology. Also in Chapter II is a set of definitions for discussing C3 which are based on the theory of combat presented. In Chapter III the student is introduced to the various types of modeling, and the modeling process. Chapter IV deals with selection of measures of effectiveness (MOE), performance (MOP) and force effectiveness (MOFE). In Chapter V the student is introduced to attrition modeling techniques using Lanchester attrition equation. Chapter VI examines the history of naval combat as and the attrition models that best emulate combat at sea in different situations. In Chapter VII non-attrition models are examined and contrasted with the attrition models presented. Chapter VIII looks at the current state of the art, including several combat models located at the Naval Postgraduate School and elsewhere, which have been used for extensive research. A summary is presented in Chapter IX to review the concepts presented and examine the material in view of the follow on courses the students of Command and Control will take.

Each chapter begins with an introduction which outlines the objectives of the chapter in simple bullet statements. A list of outside readings is presented to supplement the lectures. Following the list of readings is a section which examines each of the objectives in more detail to provide the student with the general idea behind each objective so that the student will have a feeling for what material should be obtained from each of the readings and how the objectives are related to each other.

The reading for Chapter II is contained within the chapter in order to condense several separate works into one document and tie together a theory of combat with a C3 terminology for use throughout this course.

II. COMMAND AND CONTROL & COMBAT THEORY

AIM:

Provide the student a background in combat theory, analysis and modeling. Present the student with a useable theory of combat. Present definitions of C2 and C3 which support the combat theory. Explore the role of combat analysis in making C2 decisions to support effective combat.

OBJECTIVES:

* Introduce the role of combat analysis as it applies to command and control decision making

* Develop the theory of combat to be discussed in this course
  ** Define and illustrate force
  ** Discuss combat process and how these processes have measurable results
  ** Define the different types of combat potential - designed and available
  ** Link concept of combat power on two sides with measurable results and an outcome of a battle

* Present the fundamental equation of combat power

* Provide definitions of Command and Control as a framework for applying the theory of combat
  ** Define command, command and control and a C2 system
  ** Discuss the functions of command -- organization, motivation, decision and execution

* Discuss role of C2 countermeasures as they apply to combat

READINGS:

1. Frank Snyder, Command and Control: Readings and Commentary, Session 1, Command and War, pp. 11-19.

A. OBJECTIVES FOR COMMAND AND CONTROL AND THEORY OF COMBAT

The purpose of this course is to give the student a background in combat modeling and analysis. The specific tools of modeling are not emphasized in this course as much as the principles and application of combat models to military environments. The end result of a combat model is derived from the combat analysis performed. The purpose of combat analysis is to provide a decision maker with a tool (aid) for making more informed decisions concerning his force employment and tactics.

In order to understand how combat models are "built" and used, it is necessary to understand some theory of combat and the unique terms associated with combat. The theory presented in this course outline was developed by The Military Conflict Institute for its general membership and is condensed in this paper.

Forces are those elements which are assigned to perform some function or activity directed against a given element or target. A commander may activate his forces causing a collection of activities to begin which in themselves cause processes that result in some measurable outcome. The combination of these activities creates what is called combat power.

The capacity for forces to successfully engage in combat is measured in combat potential. The combat potential of forces can be measured in terms of their designed and available potential. The designed combat potential of forces is a measurement of the capacity of those forces to engage in combat given ideal training, equipment,

organization and motivation. The available combat potential is a measurement of the current state of the forces with respect to training, equipment, organization and motivation.

Combat power is the lethal means by which one side attempts to change the states of the forces of the other side. The end result of the collection of processes is some synthesized expression, or measure, called an outcome.

The fundamental equation of combat power is suitable for explaing how the forces and the activities assigned to each element are transformed into combat power. The general form of the equation is: $P = F \{m , u\}$, where "P" represents combat power, "m" represents the number of forces of a specific type, "u" is the rate of their activity, and "F" is the command function which governs m and u.

In order to understand how combat analysis is useful in Command and Control decision making, the definitions of Command and Control must be structured in such a way to reflect the theory of combat presented. The definitions provided in JCS Pub 1 (see page 17) provide a basis for the more useful definitions developed in the next section.

In terms of the theory of combat, command is the function of generating combat potential through a collection of the activites of organization, motivation, decision, and execution. The commander is responsible for ensuring that this function is properly carried out. Command and control is the process by which orders to activate these forces are carried out such that some measurable combat power may be generated. A command and control system is the collection of

personnel, equipment and procedures the commander uses to facilitate the process of command and control.

In examining the collection of all processes each side employs to generate measureable combat power, the role of C2 countermeasures may be seen as the activity of impeding the enemy's ability to effectively activate his forces, resulting in a smaller contribution to the enemy's overall combat power.

B. PURPOSE OF STUDYING C3 AND A THEORY OF COMBAT

One of the most unique areas of interest to arise in military studies in recent years is the increased attention given to the phenomena of command and control. While command and control activities have always been present in military organizations, military theorists, strategists, analysts, and professionals now devote more time and resources to increasing the awareness of military organizations to the vast opportunities associated with improving command and control operations and facilities.

Although the terminology appears at first glance to be simple and self-defining, many different definitions of terms and concepts continue to exist among theorists and practitioners of command and control. There is, however, one common and simple idea present in each of these definitions -- that command and control involves someone who is responsible for making decisions concerning his organization and causes those decisions to be carried out. Decision making and execution, in whatever circumstance considered, can be taken as a basis for any command and control definition.

The kind of decision which must be made, and its execution, is unique to military organizations due to the very nature of military forces and the deadly environment in which these decisions are made. Military organizations are created and maintained for one reason -- to carry out the mission oriented activities and processes associated with armed conflict. Whether a military unit is formed in response to an existing threat or maintained in preparation to meet an expected or possible threat, any decision made concerning the organization can ultimately be reduced to one concept -- how do the possible choices affect the ability of forces to conduct armed conflict? Consider the following two examples of decision making:

CASE I: The CNO has to allocate money to one of two proposals before him. The first alternative is to invest money in research and development for a new generation of communication systems which will improve abilities of surface ships to communicate with submarines. The second alternative is to use the same money to improve the communications equipment on aging ships with communications equipment using current technology. The more fundamental question the CNO must consider is not a least cost or technical efficiency question but rather, how will the ability to conduct battle be improved in each case and which decision provides the greatest increase in fighting ability per dollar spent.

CASE II: A battalion commander engaged in low intensity combat in a European theatre is responsible for a 100 mile front. As fresh troops arrive in the theatre as reinforcements, the commander must decide where to place the troops in the

theatre. The decision he makes -- the placement of troops -- is ultimately based on a belief that his decision will result in an increased ability of his organization to conduct combat activities as a result of the troop placement.

In deciding how best to improve the ability of a military organization to conduct armed conflict at any given time one must be able to determine the relative worth of seemingly unrelated things. How does the CNO measure the value of a new communications system versus an upgraded communications system for the same ship? What is the result measured in combat potential of placing reserve troops 50 miles or 10 miles from an active front?

Within these questions lies a basic question every military professional is tasked with justifying: how can the benefits be measured for the different choices and opportunities currently being considered? Although this is certainly not a question which is limited to the military environment, the approach taken to answer the question is unique to military organizations. It is technically simple to determine the differences between two communication systems or to explain the differences in moving troops to specified locations, but the real problem lies in trying to assign a measure of effectiveness (MOE) to each possible case and to choose from that the best alternative using some means of analysis.

To be able to assign different values to different possibilities and make a decision which affects the ability of the organization to fight is, in fact, the basis for a command and control system. To evaluate what may appear to be unrelated factors and determine what action to take to maintain, if not improve, the readiness of the

organization to accomplish its mission, which is ultimately a mission of conflict, is the heart of command and control.

Having some idea now of a generalized purpose of command and control, we must now consider how to analyze different alternative courses of action. One means to analyze different alternatives is to model the effects of alternatives in a manner which is suited to the factors involved. In the case of military organizations the unique environment requires a unique approach to solving the problem. Since World War II, a branch of operations research, **combat modeling**, has arisen as a result of efforts in this field. No other profession deals with lethal two-sided competition in the way ours does. It applies scientific methods to combat scenarios and develops tools, called models, for simulating the environment, the processes, and the outcomes of the engagements.

Before being able to understand how combat models can be used to solve the command and control problems facing an organization, a common understanding of some terms used must be reached. Specifically one must have: (1) a simple understanding of the theory of combat to be able to apply models to a situation, (2) an understanding of what command and control means in the specific context of combat, and (3) an understanding of what models are. With this information the reader will see how command and control depends on combat modeling and analysis to make appropriate decisions.

C. COMBAT THEORY

The theory of combat and definition of C3 terms which are presented in this chapter was developed by The Military Conflict Institute, and expanded upon by Wayne P. Hughes in his paper "Command and Control Within the Framework of a Theory of Combat". The premise of the theory is that combat is a complex interaction of force-on-force activities. The concept is developed by first examining the smallest part of the military organization and building upon this structure to develop the material necessary to understand the basis of force-on-force interaction.

1. Definition Of Forces

All military organizations are comprised of <u>forces</u> which are the actual instruments of combat, specifically, personnel and equipment. Each <u>element of a force</u> may be described by a set of attributes which give details about the current state of an element. The attributes may include such items as the following: number of personnel in each element, weapons in unit, ammunition available, accuracy of personnel firing weapons, motivating factors for the unit, geographic location of unit, etc. The state of these elements will be important later in developing the theory further.

These forces may be assembled together in groups with common <u>combat functions</u>, which the units will perform as <u>activities</u>. These functions may in general be categorized into one of the following:

- Commanding forces and their activities.
- Controlling the activities.

- Gathering information for the command, control, and firing processes.
- Moving troops and units from place to place.
- Supplying the consumable goods and hardware to various locations.
- Delivering firepower to the enemy.
- Disrupting the combat functions of the enemy.

2. Force Functions And Activities

The combat functions are responsibilities or roles played by forces. They are the means with which to fight against a notional enemy without any knowledge of who the enemy is or where the battle will take place. The functions are defined independent of the environment in which any actual battle may occur.

In combat each element of a force will perform actions based on the function assigned to the element (by command), the current state of the element (capability of the element at a given time) and the attributes of the element. For example, an AAW unit will perform actions against enemy aircraft, but it is not expected to take effective action against enemy infantry or armor. The effect of the actions taken by the element is to cause some change in the state of the enemy as well as the unit itself. This change in state caused by an element-action-element exchange is known as a combat activity. The result of these activities is some change in state which can measured. For example the effect of an AAW unit firing at an approaching aircraft is a depletion of ammunition for the firing unit and a possible loss of aircraft for the enemy. Activities such as the delivery of fire, can be

quantified and measured but the reader should not think of any function as generating combat results.

Note that to this point we have talked only about the effect of one side on the other. The second side is also usually delivering fire in return, so that there is a total force-on-force effect.

3. Combat As A Collection Of Processes

The collective activities of the forces on both sides are combined into a combat process which can be measured as results. The collective firepower activities of the functional elements of a force and the countermeasures employed by the enemy have net effects (such as attrition, suppression, retreat, or other movement) on the enemy. The results of the collection of the activities of all the functional groups are changes in states of the forces on both sides.

4. Combat Potential

The capacity of a given force to engage successfully in combat against an enemy is called its combat potential. There are two types of combat potential which describe the state of a force. The designed combat potential of a force is a measure of the capacity of a given force to be effective in combating a known enemy given optimal training, equipment, motivation, organization and leadership. Design potential assumes that the forces perform as designed and intended, with a complete understanding of who the enemy is and the geographical location of the battlefield. With this information the force will be optimally fitted to the specific battle and has ideally perfect capacity to conduct the armed conflict in question. The available

combat potential of a force is the current capacity of a force at any given point in time to be effective in combating an enemy given existing levels of training, equipment, motivation, organization and leadership. Obviously, the capacity for a force to conduct warfare at any given time against a specific enemy will be less than its designed capacity due to imperfect levels of training, equipment, organization, and an imperfect knowledge of the battlefield location and motivation of the enemy. The available combat potential will thus be measured as some factor between 0.0 and 1.0 of the designed combat potential.

5. Measurement Of Combat Power

The lethal effectiveness delivered by forces is a result of those forces being activated by command against an enemy. This is the quantity called combat power and is a result of forces engaging enemy forces at a given time and location. Combat power is generated against an enemy as a result of forces carrying out combat actions against the enemy based upon a commander's activation of his forces utilizing a command and control process. The combat power is generated from available combat potential of the forces involved but does necessarily consume the potential of the forces in the way that energy is consumed from a battery during its use.

The original concept presented for what is combat may now be examined based upon the previous discussion. Force (or combat effectiveness) against an enemy will result from the collection of combat activities, grouped as combat processes, but only the enemy's attenuating countermeasures are taken into account. The forces on both sides produce some measurable change in the states of both

sides. In summary, the effect of both sides conducting these operations results in a complex interaction of lethal force-on-force which has measurable results we identify as combat.

6. Fundamental Equation Of Combat Power

Having an understanding of combat, the next step is to develop an equation for determining the relationship between the entity we desire to measure -- combat power -- and the independent variables involved. The fundamental equation of combat power for tacticians and theorists is of the form: $P = F\{m, u\}$.

The quantity, combat power [P], derives from the mission-specific relationship between force elements [m] and the kind and time rate of their activities [u]. The function [F] governs the pattern of the elements' activities, so is called the command function. In other words, when the commander activates his elements of combat potential, the "pattern" is the tasks they perform. By pattern is meant what each element is doing (firing, scouting, maneuvering, communicating, etc.), where it's doing it (flank, front, rear, enemy's rear, entrenched, etc.), and how well it's doing it (rate of fire, rate of search, speed of movement, effectiveness of communications, etc.). Since activities and combat power usually have a geographical direction or orientation, they may be shown as vectors.

In the operational sense, it is the pattern as well as the number of forces and rate of activity that determines the combat power of one side. In the analytical sense, a model that best describes the pattern of activity is chosen and is used to compute the quantity of combat power delivered.

But the effect of side A's combat power on side B depends in part on defensive actions by B's elements (entrenching, jamming, evasion, withdrawal, etc.). This is why we must distinguish combat functions ordered and performed by side A (which create raw combat power) from the two-sided process that determines the effective combat power (or "force" as it is often called in literature). Effective power by side A causes observable results, such as casualties to B, or his suppression, retreat, or surrender.

B's countermeasures to lessen the effects of A's combat power are not the same as B's offensive activities that generate his own combat power against A. Combat is a force-on-force activity because A and B are both creating combat power and attenuating the effect of their opponents' combat power.

It is the role of a commander to (a) govern the pattern of his forces' activities and (b) do so with regard for the probable pattern of enemy activity. It is the role of a combat analyst to discern probable patterns of both sides and model them in a way that will result in better command decisions.

D. COMMAND AND CONTROL

Command and control has about as many definitions as there are users. The reason for the different definitions is the many cases in which command and control is applied. A terminology to be used when discussing command and control which bridges some of the existing definitions will be presented which is consistent with the combat theory presented, and is a summary of a paper by Wayne Hughes titled "Command and Control Within a Framework of a Theory of Combat."

1. Definition Of Terms

As a starting point take the JCS Pub 1 definition of command and control:

> The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities and procedures which are employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishment of the mission.

An important weakness of the JCS definition is that there are many functions performed by the commander long before the combat mission is known. The generalized JCS definition is directed towards missions and operations and does not include all the preparatory actions which are involved prior to performing these missions. The JCS definition is, however, a useful place to start to develop a useable concept of command and control.

The JCS definition contains three different notions. The first is the *concept of "the exercise of* authority *and direction* by a properly designated commander over assigned forces in the accomplishment of the mission." This is a general statement of what command is for: its function. The second idea is that of ".. the functions performed .. and employed by a commander", which will serve as a basis for the definition of the command and control process. The third idea contained in the definition is the ".. arrangement of personnel, equipment, (etc.) ..." which is a perception of the physical entities that make up a command and control system. Each of these will now be looked at separately.

Command as taken from the JCS definition is the all encompassing responsibility associated with "the exercise of authority and direction by a properly

designated commander". To command a force from the inception of that force to the execution of operation orders requires functions including organization, motivation, decision and execution.

2. The Function Of Command

The command function that is applicable to all levels of military organizations must necessarily include these functions of organization, motivation, decision and execution. There are other categories of command which can be offered such as training and education but they may be considered as a subset of one of the four categories already presented.

In light of the theory of combat presented, command is the all encompassing function which generates the designed and available combat potential. Through the subfunctions of organizing, motivating, deciding and executing, a commander brings his forces from some untrained or otherwise unready condition to a point where the available combat potential of the forces is as near as possible to its designed combat potential. The readiness of the forces prior to executing an operation is the responsibility of commanders at many echelons and is accomplished through the function of command.

3. The C2 Process

We can also look to the JCS definition of command and control to derive a partial definition of what is meant by command and control in the "process employed by a commander in planning, directing, coordinating, and controlling forces in the accomplishment of the mission." These are the actions taken by the

commander to transform the combat potential of forces (generated by the function of command) into the realized combat power resulting from carrying out mission orders. Thus command and control is the process of achieving measurable combat power, while command is the function of generating combat potential by means of the collection of actions of organization, motivation, decision and execution.

It is important for the theory of combat that we distinguish command and control as a process of transformation, not just a function, or responsibility, to govern everything under a command. Command and control affects all elements in a command only to the point that the elements are part of the command and control system (a definition provided below) and the measured actions carried out by the elements are part of the command and control process. Command and control cannot be thought of as everything involved in combat. The process of ordering a battery to fire weapons from the moment the order is given until the time the gunner is ready to fire is contained within the command and control process. What happens when the artillery is fired and the results are achieved by the weapon is called combat. In this sense combat is an all encompassing term. Command governs all the actions of its forces, but command and control is not everything in combat.

4. Information Collection

One other exception to some definitions of command and control involves the function of information gathering. The activities associated with information gathering, including detection, classification, tracking, targeting, etc., are directed as part of the command function. Indeed, how the decision is made to distribute forces to collect this information is a vital decision which a commander must make. How

the information is interpreted once collected and deciding what actions will be taken based on the information is indeed a command and control process but the actions of collecting the information is best thought of not as part of the command and control process, but as a separate process in its own right: information collection. This point is extremely important in current command and control problems as we will see later.

5. A C2 System

Having presented definitions for the command function and the command and control process, the third step is to define a command and control system. The JCS Pub. 1 definition provides an adequate definition by emphasizing "..the arrangement of personnel, equipment, communications, facilities, and procedures which are employed by the commander..". A command and control system contains all the tangible items used to perform the process defined above. The command and control system then is composed of:

1. physical elements -- transmitters used to broadcast orders, signal lights and flags, computers, code books and tapes, deciphering equipment, etc;
2. human elements -- the commander himself, communications staff, military analysts in the chain of command, etc.;
3. procedural elements -- used to conduct the processes -- training manuals, equipment manuals, procedural manuals for a fleet, organization charts and command relationships.

A command and control system is used to facilitate the process of command and control. It is important to note the inclusion of the commander himself in the system definition. Without a commander to make decisions the system

cannot perform its function, so we must include the commander as part of the very system he uses. Even when the environment is a lone soldier in a battlefield making decisions about himself, there exists a "commander", the soldier, and a system to help him make some decision about the action he must take.

6. Role Of C2 Countermeasures

Another area which needs defining for the theory of combat to be complete is command and control countermeasures. If we define command and control as the process of transforming combat potential into combat power, then <u>command and control countermeasures</u> are those activities which a force engages in to reduce the effectiveness of the enemy's command and control. These countermeasures are actions which cause the enemy's command and control elements to be ineffective such as jamming radios, providing misleading intelligence and other such activities which help to confuse the enemy's perception of the battlefield.

A <u>command and control countermeasures system</u> includes the equipment and personnel whose activity is to carry out countermeasures such as the communications jammer and the associated operator.

E. MODELING

It was during World War II that military operations research gained its place as an emerging science. After the war the writings of Morse, Kimball, Blackett, and others who had analyzed military situations and phenomena spurred the creation of

modern military operations research. This was the first time that analysts used scientific principles applied to the environment of combat with outstanding success.

Prior to World War II there was not a school of thought or formal organization devoted to analysis of military actions or conditions, but during World War II scientists "went to war". Some became involved very early in field operations, most notably with radar in the air Battle of Britain. From there it was natural that they should involve themselves with the tactical employment of sensors and weapons. Thus operations research was born. The works of Morse and Kimball, presented in The Methods of Operation Research, 1946, still stand as a cornerstone in the field of combat modeling and analysis.

A model, applied to any situation, is merely a "simplified representation of the entity it imitates or simulates." The goodness of a model lies in how well it achieves its purpose. It is fair to say that the closer it approximates the real world entity it represents, the greater its value. But models do not reproduce war, and attempts to do so have led to overwhelming complexity with little to show for it. Complexity per se has little to do with utility in practice.

A feature of modeling is that the model is prepared with a specific need in mind to serve the client for whom the model is built. In the case of military modeling the client may be, for example, the JCS which desires to have a model created to explore the effects of nuclear detonations in an unlimited war. It is important to specify who the client is, and the person served by the model must have a fair idea of how it works and how well it fits his needs. We say a model is "decision oriented."

In developing models there are general steps which must be taken by the client as well as the modeler. In Work and Method of Operations Analysis, Robert Dorfman categorized the steps involved in analysis as:

1. Perception,
2. Formulation,
3. Observation,
4. Analysis,
5. Presentation.

These five steps are crucial in developing adequate models for military applications.

For the purposes of this course, the client wll be taken to mean a person who is in a position of command and who must make decisions. Perception of the problem as put forth by a client and as understood by the modeler lays the basis for providing a useful model as a tool for the ultimate goal of analysis. The modeler needs to understand the context for which the model is being developed. Most analyses are not intended to give a single solution as end products. Typically the result is an IF-THEN statement: if such-and-such are the inputs then so-and-so will be the results.

Formulation of the client's problem is accomplished by four actions. First, determine the objectives of the operation. Second, list the alternative courses of actions. Sometimes the list must include both one's own and the enemy's choices. Third, define a measure of effectiveness by which to compare the alternatives. Fourth, determine the variables that are regarded as critical, list them, and figure

out how they interact so that the relationships can be modeled during the steps called analysis. An agreement of the problem statement, the data available for the model and the assumptions which will be made are determined in this step prior to collecting the data and modeling the client's needs.

The next step, observation, requires collecting data to be used in the model and the environment which the model is attempting to emulate. This may often cause a reformulation of the problem if obvious changes are required to accurately describe the environment.

During the analysis and presentation steps the analyst combines his working model with the observable data in a way that "models" the situation. The user ought to participate as this is done to ensure that the model truly describes the situation.

It should be pointed out that this process may be cyclical or even done in another order. No matter what sequence, it remains necessary that each step be carried out and that the client be involved throughout. Military models are generally developed to assist in decision making. As pointed out earlier, most models do not provide a definitive answer but compare alternative choices according to an MOE. Four major modeling techniques to fit a particular situation are available:

1. Analytical representations,
2. Computer simulations,
3. Arrangement of war gaming tools and personnel,
4. Field experiments.

The pros and cons of each technique and may be found in Military Modeling, The Military Operations Research Society, Second Edition, 1989, pages 1-36.

Some examples of model types listed for military applications include: models by application or purpose (battle planning, wartime operations, weapon procurement, force sizing, etc.), models by scope or scale (micro or single unit engagement models, multi-engagement models), ad hoc and standing models and models to describe, prescribe and predict.

The use of all the above techniques when applied to military operations analysis has added a scientific grounding for making command and control decisions. This course will help to understand how modeling and analysis aid in making better command and control decisions based on increasing our combat power and diminishing that of the enemy.

F. COMBAT MODELING AS A TOOL FOR COMMAND AND CONTROL

Having defined the terminology associated with combat, command and control, and modeling, the next step is to discuss how they interact with each other.

As stated above, command and control refers to a process of transforming combat potential into combat power. The function of command is to generate maximum combat potential. Making the decisions that will increase either the combat potential or combat power of a force involves some sort of analysis. The analysis techniques and tools used vary from situation to situation.

As an example, consider the following case. A fleet commander embarked in a flagship must decide how to assign ships in the fleet to various tasks (i.e.,

functions) while steaming to battle. During the oceanic transit, surveillance is of most concern to the admiral. The admiral is faced with deciding how he will allocate aircraft between being combat ready and providing surveillance and scouting.

In this example the system to be modeled is the battle group containing the aircraft carriers, battleships, and support ships. Inputs to the system include: available aircraft of different types, fuel availability, pilots available and nonorganic surveillance data including remote sensors, satellites, etc., as resources. In addition to the resources available, other inputs are present including: rules of engagement (ROE) and directions from higher authority requiring the admiral to keep remain undetected during the transit. The output from the combat model analysis should help determine the surveillence and strike aircraft based upon the surveillence information gathered and other applicable reports.

The admiral must decide what his choices are, what tradeoffs exist, and what vlues for the measure of effectiveness for the situation should be. Using a certain aircraft for surveillance means that the aircraft is not available for a strike if it should be required. For his MOE, the admiral chooses to base his decisions on his ability to provide "sufficient" surveillance while retaining "sufficient" strike power.

The role of combat analysis is now to simulate the battle group with a highly specialized model which the admiral can use to change the number of aircraft used for surveillance as well as their search plan (radial and circumferential coverage) and see the resulting probability of detecting air, surface, and subsurface attackers. At the same time he has a strike plan, derived from analysis, which tells him how many aircraft will be necessary to attack a variety of targets. The combat modeler

must be familiar with the interrelationships between all the input variables to provide an accurate model for the admiral. The admiral still retains full responsibility of a final judgement and decision.

The ability to determine these interrelationships requires experience not normally found in business or other type modeling. Due to the very nature of combat, specialists in the field of combat analysis must be used who are familiar with the various relationships that exist and the "laws" governing these relationships. This is the art of combat analysis and the trait that those in a position of command seek out to help them make decisions unique to the military environment.

The goal of this course is to provide the student with a background in the understanding of these combat modeling tools and techniques and an ability to work with the analysts who provide useful information to the commander.

G. REVIEW QUESTIONS

1. Distinguish between a function and a process as it relates to combat.
2. Define the terms command, command and control, and command and control system.
3. Identify the elements of a command and control system. What is an element's "state"? Explain why a surveillance system should not be considered as a component of the command and control system.
4. Describe the significance of the three components of the "element-action-element" model of combat. How are the two elements related? Is this a model of a process or a function?
5. Is it possible to measure combat force directly? Identify two alternate methods of measuring combat force.

6. Explain the difference between designed combat potential and available combat potential. Give several factors which may account for differences between the two potentials.

7. The fundamental equation of combat power defines combat power as a function of missions (actions) to be performed and units (elements) to perform those missions. How does command and control enter into this function and what are the effects of command and control on achieved combat power?

8. You have been told that the use of command and control countermeasures is a process. Illustrate this with three examples.

III. MODELING

AIM:

Provide the student with an understanding of the various types of models and the characteristics of these models. Emphasize the fact that modeling is a product to aid the decision maker. Discuss the role of the modeler in useful analysis.

OBJECTIVES:

* Definition of a model

* Purpose of modeling is to support decision making to improve performance and make better decisions

* Discuss the general uses of models -- as a decision aid, research tool, and a training tool

* Understand characteristics of a good model

* Discuss the types of models

* Discuss the modeling process

* Discuss the factors affecting model validity -- faulty data, faulty model and faulty reasoning or logic

* Effective combat modeling must be accomplished by "professionals"

* Emphasize the limitations of models

  ** Distinguish between approximation and abstraction

  ** All models are IF - THEN statements -- importance of assumptions

* Discuss methods and consequences of data collection

  ** Understand the effect of the wartime setting on data collection

  ** Definition of "dirty data"

* Discuss the principles of proper model selection

  ** Emulate the physical phenomenon

  ** Keep the model simple, yet adequate (apply reasonableness test)

  ** Keep decision to be made in view -- ensure model reflects the decision

READINGS:

1. Hughes, Military Modeling, pp. 1-48.
2. Levis, "Modeling and Measuring Effectiveness of C2 Systems", pp. 15-17.
3. Giordano and Weir, A First Course in Mathematical Modeling, pp. 29-40.
4. Wylie, "The Calculation of Risk".

5. Morse and Kimball, Methods of Operations Research, pp. 38 and 52-53 (see the readings for Chapter IV).

A. DEFINITION AND PURPOSE OF MODELING

"A Model is a simplified representation of the entity it imitates or simulates" [Hughes, Military Modeling, pg. 1]. The goal of modeling is to strip away the superfluous detail and complexity of reality and lay bare the underlying variables, constants and relationships in order to draw conclusions, make predictions or support decision making. Specifically, the aim of military modeling is the study of combat forces to support decision making relevant to force structure and force employment. The purpose of military modeling, and modeling in general, is to provide a more solid basis for decision making with the goal of improving performance and the quality and timeliness of decisions made. "A model is useful if a better decision can be made with the information that it adds" [Hughes, Military Modeling, pg. 17].

B. USE OF MODELS

Three fundamental uses of military models are decision aids, research tools, and training tools. The principal applications of these tools deals with the following force structure concerns [Hughes, Military Modeling, pp. 23-33]:

1. Battle Planning -- to improve tactics, operations or force composition.
2. Wartime Operations -- to solve time-sensitive questions.
3. Weapon Procurement -- to apply principles of systems analysis to yield cost-effective selection of competing weapon systems.
4. Force Sizing -- to help determine force mix, identify or establish trends, or project future requirements.
5. Human Resources Planning -- to support management decision making primarily in the area of personnel and training.

6. Logistics Planning -- to project logistics requirements and optimize logistics support.

7. National Policy Analysis -- to assess the impact of broader policy decisions on military concerns.

Since models are used to support decision making, their utility is most beneficial when they accomplish one or more of the following [Hughes, Military Modeling, pg. 14]:

1. explore issues in an orderly way,
2. structure and discipline the debate,
3. compare and contrast alternatives,
4. reveal new characteristics,
5. lead to unexpected, but valid conclusions.

C. CHARACTERISTICS OF GOOD MODELS

The principal measure of a model's usefulness is its ability to communicate the attributes of the phenomena under study. The ability to communicate is constrained by several characteristics, the foremost of which are transparency, flexibility, and reproducibility [Hughes, Military Modeling, pg. 24]. Transparency refers to the ease with which the intended user can understand the model and its results. Simplicity and transparency both facilitate model modification. Flexibility refers to the ease with which a model can be adapted to varying situations, as well as wide ranges of input data. Reproducibility refers to the ability of a model to generate the same

results using the same data each time the model is applied. Additionally, the results must be independent of the individual that applies the model. Military Modeling lists a total of 14 characteristics of military models based on findings of the Army Models Review Committee (AMRC) [Hughes, Military Modeling, pg. 7]. However these three, flexibility, transparency and reproducibility, together with relevancy (roughly, how much insight is enough) provide a framework for measuring a model's utility and validity.

Though credibility is a characteristic unto itself, according to the AMRC, Alexander Levis sets it in the forefront of model evaluation issues [Levis, "Modeling & Measuring Effectiveness of C3 Systems"]. Levis holds that the credibility of a model is a function of its coherence, corresponding clarity, and workability. These address the extent to which the model variables and assumptions are verified, the degree to which the model outputs agree with anticipated outcomes, and the ease with which the model communicates the problem analysis. The ultimate test of a model's credibility is the willingness of the decision maker to apply the result of the model in sensitive analysis.

D. THE ANALYSIS AND MODELING PROCESS

The fundamental methodology of model development follows closely the classical approach to scientific problem solving. One approach to this methodology is described by Clayton Thomas [Hughes, Military Modeling, pg. 63] where he discusses the findings of Robert Dorfman, who recall, divides the analysis process into five stages:

1. Perception -- recognition that a problem exists and the generation of a problem statement.

2. Formulation -- determination of what is to be measured and the generation of a hypothesis, frequently expressed as a measurement of effectiveness.

3. Observation -- collection of data upon which to validate the model or generate conclusions.

4. Analysis -- test the hypothesis against the observed data.

5. Presentation -- recommendation of a course of action or decision based upon analysis of data and hypothesis.

A similar approach to modeling is given by Giordano and Weir [Giordano and Weir, A First Course in Mathematical Modeling, pp. 29-40] where the generation of an acceptable model is the result of an iterative application of the following steps:

1. Identify the problem,

2. Make assumptions -- determine variables, constants and relationships,

3. Interpret the model -- state in concise terms,

4. Verify the model -- check reasonableness and validity of results,

5. Implement the model,

6. Maintain the model.

The heart of modeling lies with the correct identification of the problem or situation to be studied and the correct identification of the more significant variables and the relationships between them. "The great art of modeling is to identify the primary relationships pertinent to the issue, isolate them, and study their effects" [Hughes, Military Modeling, pg. 14].

E. FACTORS AFFECTING MODEL VALIDITY

Three principal factors which may cause a model to be invalid are faulty reasoning or logic, a faulty model, or faulty data.

Faulty reasoning or logic results from incorrectly identifying the problem to be studied or omitting significant variables pertinent to the problem. The modeler's judgement and expertise are critical to successful model generation [Hughes, Military Modeling, pg. 41]. See Capt. Wylie's article for an example of faulty reasoning in model generation. Hughes holds that combat modeling must be accomplished by professionals.

F. UNDERSTANDING THE LIMITATIONS OF MODELS

A faulty model results from the failure to identify the correct objective statement (measurement standard) for a given problem statement. See Morse and Kimball's analysis [pp. 52-53] of antiaircraft guns on merchant ships as an example. Secondly, because models are based on limiting assumptions they become IF-THEN statements [Hughes, Military Modeling, pp. 43-48]. This means that as long as the limiting assumptions hold then the model may be valid. However, when the model is used outside the bounds of its limiting assumptions the results must be suspect. A third factor in model validity is the notion of approximation and abstraction. Payne differentiates between these two notions and identifies their impact on model validity [Hughes, Military Modeling, pg. 315]. He points out that at best models only partly and incompletely represent reality and their accuracy is a function of the model's fidelity. The result will be errors because the model is less than -- only an

abstraction of -- the thing it represents. Additionally, the error due to mathematical calculations, according to Giordano and Weir, can be attributed to round off error (computer induced), and truncation error (a finite representation of an infinitely series of terms) [Giordano and Weir, A First Course in Mathematical Modeling, pg. 89]. These computational errors are what Payne calls approximations.

Abstraction errors are the result of limiting the complexity of the real situation to a level which can be modeled. Thus, factors which may be relevant to the situation being modeled may be omitted from the model in order to keep the model understandable and workable. Giordano and Weir term this phenomenon as "formulative error".

In some cases the abstraction may also be deliberate: the analyst may view the additional "error" as acceptable because the model's accuracy is only rough to begin with and the simplification aids in computations. Linear programming is an example of a powerful optimization technique that assumes that linear relationships always exist between variables; this is always a chancy assumption when modeling the real world, but it is good enough in many circumstances.

G. DATA COLLECTION

Faulty data may affect the model in several ways. First, if inaccurate data is used to generate the model the assumption made regarding relationships between variables based upon the sample data may be inaccurate. Secondly, if inaccurate data is used to verify or validate a model, the model may be certified which when used with more accurate data may generate faulty conclusions. Giordano and Weir terms

this limitation on model accuracy as "measurement errors" [Giordano and Weir, A First Course in Mathematical Modeling, pg. 89].

Data collected to support combat modeling is especially susceptible to measurement errors due to the nature of combat. Use of cover and concealment and deception result in inaccuracies in measuring enemy losses. The tempo of battle results in poor measurement and recording of friendly losses. Additionally, environmental factors may preclude any measurement. Thus, combat data must be viewed with skepticism. Because of the nature of this dirty data, the wartime analysts Morse and Kimball argued for making changes in tactics only when at least a three fold net increase (a hemibel difference) in performance could be anticipated [Morse and Kimball, Methods of Operations Research, pg. 38].

The importance of data in model accuracy is highlighted by Lieberman in an analysis of National Policy Modeling [Hughes, Military Modeling, pg. 252]. He holds that discrepancies between model results are typically due to differences in input data or assumptions.

H. PROPER MODEL SELECTION

The final selection or generation of a model is governed by three simplified principles:

1. Keep the decision maker and the decision to be made in perspective. Key issues are timeliness and understandability.
2. Keep the model as simple as possible, yet sufficient in detail to adequately reflect the environment being analyzed. According to Weir the model must be reasonable, that is "does it agree with common sense?"

3. The model must emulate the physical phenomena being analyzed. Personal perceptions or biases introduced by either the client or the analyst will hinder the model's validity.

I. REVIEW QUESTIONS

1. Define modeling and state its purpose.

2. Identify the fundamental uses of modeling.

3. Distinguish between the five different types of models and give an example for each category.

4. Give several ways in which models can be used to support decision making.

5. Given that the ability of a model to communicate provides a measure of its usefulness, explain why the model's transparency, flexibility, and reproducibility can affect its value. Explain why its fidelity can hinder its value.

6. Discuss the underlying importance of a model's credibility.

7. Compare and contrast the steps in an analysis as defined by Dorfman and Weir.

8. Identify the three factors which affect a model's validity, the stage(s) in the model development in which each is likely to occur, and measures which may be taken to mitigate their effects.

9. Distinguish between an abstraction and an approximation. Determine when they might be desirable.

10. What factors must be considered when determining a model's appropriateness or suitability?

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IV. MEASURES OF EFFECTIVENESS, PERFORMANCE, AND FORCE EFFECTIVENESS (MOE/MOP/MOFE)

AIM:

Define MOP, MOE and MOFE. Ensure the student understands the differences and similarities between variables and parameters in terms of equipment characteristics (or capabilities), system performance, and operational (or organizational) effectiveness.

OBJECTIVES:

* Define Measure Of Effectiveness (MOE), Measure Of Performance (MOP) and Measure Of Force Effectiveness (MOFE)

* Show how the use of MOEs are a logical consequence of modeling techniques to efforts geared towards improving the effectiveness of combat operations

* Show how the choice of MOE is dependent upon the phenomena being modeled -- either as a one-sided, force-on-force or hunter-evader model

* Examine analyses developed by Morse and Kimball during World War II showing how MOE's were developed based on the following concepts:
  ** Sweep Rates
  ** Exchange rates
  ** Comparative performance
  ** Equipment performance evaluation

READINGS:

1. Rockower, "Notes on Measures of Effectiveness", pp. 1-6.
2. Sweet, et. al, "Command and Control Evolution Workshop", pp. 2.4-2.8.
3. Morse and Kimball, Methods of Operations Research, Chapters 1,3.
4. Clayton Thomas, "MOE's ... Origins, Evolution, Roles", pp. 1-12.

A. DEFINITION OF MOE/MOP/MOFE

Performance and effectiveness measurements provide a quantitative means of determining the extent to which mission requirements are being met, the degree to which a system is affecting the environment in which it is operating, or the impact an operational decision is having upon combat outcomes. In order to support better decision making Rockower [Rockower, "Notes on Measures of Effectiveness", pg. 2] asserts that one must "establish a consistent, quantitative, measurable, and credible measure ... of the value of alternative courses of action ..." These measures may assess the value of the system in terms of design specifications, functional operation or mission enhancement. According to Sweet [Sweet, et. al, "Command and Control Evolution Workshop", pp. 2-6] these measures are:

1. Measures of Performance (MOP) -- function of the system's attributes;
2. Measures of Effectiveness (MOE) -- function of the system's performance within the environment;
3. Measure of Force Effectiveness (MOFE) -- function of system effectiveness in a force structure.

B. IMPROVING EFFECTIVENESS OF COMBAT OPERATIONS

Morse and Kimball asserted that, prior to World War II, tactics and strategy were strongly influenced by environmental factors and little quantitative measurement of decision variables was possible [Morse and Kimball, Methods of Operations Research, pg. 2]. They said that the principle purpose of operations research is to analyze tactics, strategy and equipment and the operations in which

these are applied. Prior to the organization of the Operations Research Group (ORG) in April 1942 most scientific contributions to warfare advancement were in terms of new "gadgets" vice better usage of current weapons [Morse and Kimball, Methods of Operations Research, pg. 1]. The ORG supported:

1. evaluation of new equipment, to include development of tactics to enhance their employment;
2. evaluation of operations;
3. evaluation and analysis of tactical problems;
4. analysis of strategic planning;
5. provide research and development liaison.

According to Morse and Kimball the principal goal of OR is to improve the efficiency (effectiveness) of current and future operations.

Clayton Thomas [Clayton THomas, "MOEs -- Origins, Evolution, Roles"] identifies two principal uses for measures of effectiveness: as an indicator to enhance understanding of an operation or improve its performance; or as an optimizer, used to determine or select the best alternative. Thomas summarizes Omand Solandt's account of the use of MOE's in World War II as a three stage process [Clayton Thomas, "MOEs -- Origins, Evolution, Roles", pg. 4]:

1. discover the purpose of the operations, i.e., describe it,
2. determine some means of measuring its effectiveness,
3. try to improve its effectiveness.

C. DEPENDENCE UPON PHENOMENA BEING MODELED

To measure the effectiveness of an operation Morse and Kimball proposed the use of MOE's for comparing the observed operations with theoretical outcomes, friend versus foe, exchange rates, and operational results between different systems.

In striving to find the "constants of an operation" and determining how changes to them affect operations, Morse and Kimball demonstrate their use of MOEs in World War II analysis to be indicative in nature. Their goal was not to optimize combat operations, but rather to improve the use of tactics and equipment.

The selection of an MOE/MOP/MOFE is critical to performing a valid analysis of a system or operation. The choice of MOE is often determined by examining the situation to be analyzed and the interaction of forces as either:

1. One-Sided: measures changes to situation due to actions of only one side. No response is considered by the opposing side. Most logistics (supply, medicine, repair) is of this nature.
2. Force-on-Force: Players on both sides take actions affecting the situation to be analyzed.
3. Hunter-Evader: The aggressor player takes action to discover or destroy his opponent, while the nonaggressor takes action simply to avoid detection. Much of ASW is of this nature.

A special case of the hunter-evader activity is the predator-prey situation where the hunter seeks the evader with the intent of capture or destruction. In this case the prey (evader) has some means to fight back and inflict casualties on the hunter. Thus this action has some of the characteristics of the force-on-force case.

D. WORLD WAR II EXAMPLES

1. Sweep Rates

One of the first analyses examined by Morse and Kimball involved sweep rates. They suggested measuring the effectiveness of area searches by comparing the operational values observed to the theoretical values computed. The equations for these values are given as [Morse and Kimball, Methods of Operations Research, pg. 89]:

Q_{op} = (C/N)(A/T) measured in square miles/hour

C = number of contacts

N = number of enemy in area

A = total area searched (sq miles)

T = total search time (hours)

(N/A) = the average density of enemy in the area (enemy/sq mile)

(C/T) = number of contacts observed per unit of search time

Q_{th} = 2 R V measured in square miles/hour

R = effective lateral range

V = average speed of aircraft

Note that (C/N) is the ratio of contacts made to the expected number of contacts in the area. If (C/N) > 1 then some of the enemy were contacted more than once. If (C/N) < 1 then some of the enemy were not contacted at all.

By taking the ratio Q_{op}/Q_{th} a dimensionless factor results giving the net effectiveness of the search activity:

$$\frac{Q_{op}}{Q_{th}} = \frac{(C/N)(A/T)}{2\,R\,V} = \frac{C\,A}{2\,R\,V\,N\,T}$$

Sweep rates may be used when measuring one sided search activities or hunter-evader activities where the evasion tactics of the non-aggressor serve to limit the effectiveness of the aggressor's search. However, when the non-aggressor takes action to destroy the aggressor then exchange rates should be considered rather then sweep rates.

2. Exchange Rates

The use of exchange rates in combat analysis allows a consideration of whether or not the calculated or expected losses incurred during a battle justify the outcome [Morse and Kimball, Methods of Operations Research, pg. 45]. Assuming similar equipment on both sides, the exchange rate is simply:

Exchange Rate = l/k

l = number of enemy losses

k = number of friendly losses

The ratios of units lost to units engaged are:

(k/m) and (l/n)

m = number of friendly units engaged

n = number of enemy units engaged

Factors affecting exchange rates which are not typically part of the equation include the training and experience levels of the participants and the equipment types included in the engagement.

When high value targets, such as merchant convoys, are being pursued by aggressors, such as submarines, an important effectiveness measure is encounter and engagement rates. However, when the high value targets are protected by active friendly forces, the appropriate effectiveness measure becomes an exchange rate. Morse and Kimball examined the practice of escorting merchant convoys as an example of exchange rate measurements [Morse and Kimball, Methods of Operations Research, pg. 46].

3. Comparative Performance

Another use of MOE's examined by Morse and Kimball provided a means of comparing the relative effectiveness of separate tactics or weapon systems. The difficult task here as cited by Morse and Kimball is to determine a meaningful unit of measurement. The analyst must be able to determine what phenomena are critical and determine how these are affected by the various tactics or weapon systems being analyzed. As examples of the method of comparative effectiveness Morse and Kimball analyzed the impact of antiship weapons on ship design and bombing of U-boat pens versus escorting convoys (whether the best use of aircraft in the protection of merchant shipping is as ASW platforms, interdiction, or close air support).

4. Analyzing Equipment Performance

Finally, Morse and Kimball applied the MOE methodology to assess the performance of a weapon system. Four factors were identified which are relevant to measuring the effectiveness of a weapon system [Morse and Kimball, Methods of Operations Research, pg. 52]:

1. Cost - "Is the new weapon system worth obtaining and using at all?"
2. Employment - "When and where should the new system be used?"
3. Maintainability - "Is the new equipment easy to maintain in operation?"
4. Training - "How much and what kind of training is needed in order that the new weapon be more effective than the old one?"

Morse and Kimball cited the use of anti-aircraft guns on merchant ships, anti-torpedo nets, depth charge settings, and supervised practice as examples of MOE's being used to assess equipment performance.

E. REVIEW QUESTIONS

1. Distinguish between a measure of performance, a measure of effectiveness, and a measure of force effectiveness. As these measurements are not mutually exclusive, give an example of a measurement which is both a measure of effectiveness and a measure of performance.
2. Distinguish between a force-on-force model and a hunter-evader model. Give an example of each. What is the impact on the model when an evader is able to retaliate and inflict injury upon the hunter?
3. Justify the underlying purpose of the efforts of Morse and Kimball in World War II analysis in that they attempted to improve tactics and operations and not optimize combat operations.
4. Contrast the use of MOE's as indicators and optimizers.

5. Compare the three stage process of MOE development with the methods of model generation proposed by Weir, in section "F" of Chapter III.

6. Given that a scout plane has an average speed of 200 mph and can observe objects at a distance of 10 miles, what is its theoretical sweep rate? If the average density of enemy targets in the area of coverage is 0.0125 targets per square mile and the historical records indicate that the operational sweep rate is 65% of the theoretical, how many contacts can be expected in a 3 hour search? If the scout plane's effectiveness increases to 95% with a 25% reduction in speed, is the change warranted in terms of contacts made in a three hour period? How many contacts would have to be made in a three hour period to achieve an operational sweep rate of 100%? On what basis might the observed sweep rate actually exceed the theoretical sweep rate?

7. One of the decisions studied by Morse and Kimball was whether to install anti-aircraft guns on merchant ships. Identify two possible reasons for these installations and the MOE associated with each reason. Analyze the reasonableness of the installation in terms of the four factors given for evaluating equipment performance.

V. ATTRITION BASED MODELS

AIM:

Introduce the student to elementary force on force models. Introduce attrition models which rely solely on casualty ıates to determine outcome of battle. Provide the students with attrition formulas as tools for early combat analysis. Provide the student with examples to ensure an understanding of the equations.

OBJECTIVES:

* Show that attrition models are based on simultaneous infliction of casualties

* Present the logic and conditions for Lanchester's laws
  ** The linear law equation
    *** Discuss the concept and application of area fire
    *** Discuss the alternative application - a series of duels
  ** The square law equation
    *** Discuss the concept and application of aimed fire (concentration of firepower)
    *** Present Hughes' approximation to square law for engagements where losses are < 15%
    *** Introduce analysis of Iwo Jima and model validation
  ** The concept of mixed laws

*** Discuss the application of mixed laws in modern combat

** Limitation of Lanchester Laws

* Present law of exponential decay in combat

** Discuss application of law -- use example of Guadalcanal, and Napoleon's march to Moscow

** Discuss Schneider's theory of exponential decay -- the significance of the effectiveness coefficient

* Provide the student with an opportunity to use laws in examples

* Communicate the limitations and applicability of attrition models

** Discuss idea of movement/suppression/domination vs. attrition

** Discuss shock and mass and the need for treatment of "salvoes" or "pulses" of combat power

** Surprise is hard to model

READINGS:

1. Washburn, "Lanchester Systems", pp. 1-10.
2. Lindsay, "Lanchester Equations", pp. 1-23.
3. Schneider, <u>Exponential Decay of Armies in Battle</u>, pp. 100-126.

A. SIMULTANEOUS INFLICTION OF CASUALTIES

Early attempts at modeling the combat process used the attrition of forces as a measurement of effectiveness to account for or predict battle outcomes. Attrition modeling relates the rate of change of the number of forces on each side and integrates these rate of change equations to provide a state equation which can be used to determine the remaining number of forces on each side at any given time.

B. LANCHESTER LAWS

Frederick Lanchester derived two separate equations to account for battle outcomes based upon attrition rates. Each of his two equations can in themselves emulate two different combat situations. [Lindsay, "Lanchester Equations", pg. 1]

1. Linear Law [Washburn, "Lanchester Systems", pg. 9; Lindsay, "Lanchester *Equations*", *pp. 2-5*]

This law models the effects of "ancient" hand-to-hand combat where a battle was essentially a series of independent duels to the death between exactly two combatants. As one combatant triumphed over one opponent another would take his place until the succession of duels eventually left one side completely eliminated. The second combat situation this law can be applied to is the exchange of fire between forces where neither side can effectively target the other side. In effect, each force is firing an "area fire" pattern in an effort to inflict casualties by the laws of probability.

The rate of change form of the area fire linear law is:

(1) $$\frac{dB}{dt} = -\alpha_R BR \quad ; \quad \frac{dR}{dt} = -\alpha_B RB$$

where: B = Blue force strength α_B = Effectiveness of B

R = Red force strength α_R = Effectiveness of R

These rate equations yield the state equation of the linear law as follows:

$$\frac{B_o - B_t}{R_o - R_t} = \frac{\alpha_R}{\alpha_B}$$

where : B_o, R_o = initial force strengths

B_t, R_t = force strength at time t

The final result of the battle can be predetermined by examining the following ratios:

(2) $$\frac{B_o}{R_o} \{ = , > , < \} \frac{\alpha_R}{\alpha_B}$$

If : "=" then outcome is a draw

">" then blue will eliminate red

"<" then red will eliminate blue

2. Square Law [Washburn, "Lanchester Systems", pp. 6-9]

When either side is able to concentrate his forces or fire upon the opponent (when one-on-one combat no longer applies) or is able to effectively target any and all of the other side, then the linear law no longer emulates the combat. In this situation the ability of forces to provide "aimed fire" at the enemy becomes

significant and a new equation must be employed to account for the improved fire and infliction of casualties.

The name of the law is derived from the fact that the squares of the fighting strengths appear in the state equation. The significance of the model is the fact that the number of combatants engaged has greater influence on the outcome of the battle than the attrition effectiveness of the combatants. The ability to aim fire at the enemy results in a squaring effect of the number of forces fighting in a battle.

The rate of change form of the square law is:

(3) $$\frac{dB}{dt} = -\beta_R R \quad ; \quad \frac{dR}{dt} = -\beta_B B$$

where : B , R : represent force strength of (B)lue and (R)ed

β_B, β_R : attrition effectiveness coefficients of (B)lue and (R)ed

The rate equations yield the state equation of the square law:

(4) $$\frac{B_o^2 - B_t^2}{R_o^2 - R_t^2} = \frac{\beta_R}{\beta_B}$$

where : B_o , R_o : represent initial force strengths

B_t , R_t : force strengths at time t

The final result of the battle can be predetermined by examining the following ratios:

$$\frac{B_o^2}{R_o^2} \; \{ = , > , < \} \; \frac{\beta_R}{\beta_B}$$

if : "=" then outcome is a draw

">" then blue will eliminate red

"<" then red will eliminate blue

3. Hughes' Approximation To The Square Law

While the Lanchester square law provides a straight forward means of determining force strength and outcome in a battle of annihilation, the fact is obscured that most of the square law advantages accrues to the winner towards the end of the battle. From history we know that average land battle will be broken off when casualties are about 10% and even in a major battle casualties seldom exceed 30%. For battles when casualties are less than 20%, a linear approximation of the square law will serve. For equation (3) on page 55 we substitute:

$$(5) \qquad \frac{\Delta B}{\Delta T} = -\beta_R R_o \ ; \ \frac{\Delta R}{\Delta T} = -\beta_B B_o$$

where ($\Delta B/\Delta T$) and ($\Delta R/\Delta T$) are the losses , Bo - Bt and Ro - Rt respectively, at ΔT, the time the battle is over. A comparison of the calculated results with the formal square law will demonstrate that the difference is negligible for most ground battles.

The corresponding state equation is:

$$(6) \qquad \frac{B_o - B_t}{R_o - R_t} = \frac{\beta_R R_o}{\beta_B B_o}$$

where: B_t, R_t : are the survivors of Blue and Red at time (t).

Simply stated, in the early stages of a battle in which aimed fire conditions hold, the ratio of blue losses to red losses is the inverse of the ratio of the product of their respective attrition coefficient and initial force strengths.

4. Mixed Laws [Lindsay, "Lanchester Equations", pg. 9]

Deitchman [Lindsay, "Lanchester Equations", pg. 9] suggested the combination of Lanchester's linear and square laws to model the outcome of a battle where only one force is able to concentrate or aim its fire. Typical applications of this type of mixed law include amphibious assaults, ambushes, and guerilla tactics. The attrition equations for this law are:

(7) $\frac{dR}{dt} = -\beta_B B$ (from the square law); and

$\frac{dB}{dt} = -\alpha_R BR$ (from the linear law).

The resulting state equation is:

(8) $$\frac{B_o - B_t}{R_o^2 - R_t^2} = \frac{\alpha_R}{2\beta_B}$$

Assuming that B is able to continue the aimed fire and R is unable to seek cover or transition to aimed fire themselves, the outcome of the engagement may be predicted by:

$$\frac{B_o}{R_o^2} \{ >, <, = \} \frac{\alpha_R}{2\beta_B}$$

where: "=" results in a draw

">" Blue wins

"<" Red wins

5. Limitation Of Lanchester's Laws

All of the Lanchester attrition equations presented have similar limitations. The fundamental difference between the linear and square law applications is the degree of control the commander is able to attain and maintain over his troops and the situation. In his discussion of the effects of suppression Schneider observes that "the square law ... assumes absolute and simultaneous projection of force upon a target. In land warfare this projection is usually relative and only simultaneous at the decision point." [Schneider, Exponential Decay of Armies in Battle, pg. 88] This agrees with Hughes' assertion that combat is the functional, temporal, and spatial application of force. Thus, the underlying assumption of Lanchester's square law which requires the action of each combatant to be controlled is frequently violated in actual combat. This failure of control results in a breakdown not only in the targeting function, which causes a transition from aimed (concentrated) fire to area (individual) fire, but also in the ability or willingness of individual combatants to engage the enemy.

6. Solved Problems

Glenn F. Lindsay's article "Lanchester Equations" presents several exercises for understanding the Lanchester equations. Three of the problems are presented here with solutions so that the reader may see how the equations are used.

PROBLEM 1:

Given: Initial Red Force strength, 100.

Initial Blue Force strength, 120.

Red and Blue use aimed fire with kill rate 0.1 and 0.08, respectively.

A. Determine the expected winner of a fight to the end.

$B_o^2/R_o^2 = 14400/10000 = 1.44$

$\beta_R/\beta_B = 0.1/0.08 = 1.25$

Thus, $B_o^2/R_o^2 > \beta_R/\beta_B$, which implies Blue wins.

B. Determine the final strength of the winner.

$\frac{Bo^2 - Bt^2}{Ro^2 - Rt^2} = \frac{\beta_R}{\beta_B}$, thus $\frac{14400 - B_t^2}{10000 - 0} = \frac{0.1}{0.08}$. Therefore,

$B_t^2 = 14400 - 10000(1.25) = 1900$. Hence, Blue survives with 43.58 troops left.

Note that this shows one of the limitations of the Lanchester model, in that it models a continuous loss curve as opposed to a discrete steploss curve.

C. Determine how many elements Red would have needed to achieve a victory.

For Red to win requires $\frac{B_o^2}{R_o^2} < \frac{\beta_R}{\beta_B}$. Thus, $\frac{14400}{R_o^2} < \frac{0.1}{0.08}$.

Therefore, $R_o^2 >$ 14400(.8). Hence red needs at least 108 elements to dominate Blue.

PROBLEM 2:

Given: Red Force ambushes Green; Red uses aimed fire, Green responds with area fire.

Initial Green strength, 150 men: Red, 25 men.

Red firing rate is 40 shots per minute, with a single shot kill probability of 0.2.

Red is dispersed over 1000 square feet.

Area of each Red troop exposed, 0.2 square feet.

Green's probability of a kill against Red given a hit is 0.5.

Implies:Red attrition coefficient is (40)(0.2) = 8.

A. Find the critical value for Green's rate of fire. That is, at what rate of fire by Green does the outcome of the battle change?

For parity, $\frac{R_o}{G_o^2} = \frac{\beta_G}{2\alpha_R}$. Thus, $\beta_G = 16(25)/22500$.

But, $\beta_G = \frac{(\text{rate fire}_G)(\text{exp area}_R)(\text{p(kill given hit}_G))}{(\text{Red dispersal area})}$.

Hence, the Green rate of fire is:

16(25)(1000)/(.2)(.5)(22500) = 177.8.

Therefore, if Green maintains a firing rate of 178 shots per minute Green will win. If Green's firing rate drops to 177 then Red will win.

B. Determine the effect of changes to Green's rate of fire on Red's residual strength. (Assume Red victory)

$$R_t = R_o - \frac{\beta_G(G_o^2)}{2\,\alpha_R}. \quad \text{Thus, } R_t = 25 - \frac{rate_G(.2)(.5)(22500)}{2(8)(1000)}.$$

This equation is linear with respect to R_t and $rate_G$.

PROBLEM 4:

Given: Combatants in wagon train - 50 men. Indian combatants - 100 men.

Probability of a hit by wagon train members is three times that of the indians.

Firing rates are equal for both sides.

Help arrives for the wagon train when wagon train men are reduces to 25.

Arriving cavalry forces have the same rate of fire and hit probability as the indians.

A. How many cavalry men need to be sent to defeat the Indians if the cavalry arrives when there are only 25 wagon train members left?

$$\frac{(W_o2 - W_t^2)}{(I_o^2 - I_t2)} = \frac{\beta_I}{\beta_W}; \quad \frac{(50^2 - 25^2)}{(100^2 - I_t^2)} = 3$$

Solving for I_t gives the number of Indians remaining to be 66, so the number of cavalry men needed will be 67 (assuming the rate of fire and accuracy is the same for the cavalry as it is for the Indians).

B. If only 60 cavalry men are sent to assist the wagon train will there be any survivors of the wagon train party when all battles are completed?

Assuming the Indians focus their attention to the cavalry first then the number of Indians remaining after the cavalry is defeated is determined by:

$\frac{(66*66 - I_f^2)}{(60*60 - 0)} = \frac{1}{1}$; so I_f = 28 Indians remaining.

Using Lanchester equations to solve for the winner in a battle between 28 Indians and 25 people in the wagon train gives:

$\frac{(25*25)}{(28*28)} \underline{\ ?\ } \frac{1}{3}$; since 0.7972 > 0.333 the wagon train will win.

The number of wagon train survivors is determined by:

$\frac{(25*25 - W_f^2)}{(28*28 - 0)} = \frac{1}{3}$; solving for W_f gives 19 wagon train survivors.

The incremental nature of this problem highlights the difference between the actual discrete nature of attrition and the continuous nature of the Lanchester model. While round off error is small at each step, it could become significant for larger scale models based upon Lanchester attrition algorithms.

C. EXPONENTIAL DECAY

When control of targeting diminishes the probability that a given target receives more than one fatal or disabling hit increases and the net effectiveness of the fire decreases. As command, leadership, and control over individual shooters diminishes, the ratio of active elements to inactive elements also declines. Those

elements not providing fire then become "passive targets". In studying the works of BGen S.L.A. Marshall, Schneider concluded that only 15-25% of a unit would fire their weapons and then not all of those would fire them with any constancy or control [Schneider, Exponential Decay of Armies in Battle, pp. 100-107]. He further concluded that when the limitations imposed upon combat operations by imperfect command and control and inactive shooters are taken into account, the linear law should be modified by dropping the factor reflecting the number of enemy shooters [Schneider, Exponential Decay of Armies in Battle, pp. 108-114]. The resulting rate of change equations then become:

$$\frac{dB}{dt} = -\delta_R B ,$$

$$\frac{dR}{dt} = -\delta_B R .$$

These equations imply that the loss of force is proportional to the size of the force. Thus, while Lanchester holds that superior numbers result in superior results, this model implies that a large force can expect greater losses than a small force. When integrating these rate equations the resulting state equations become:

$$B_t = B_o \exp[-\delta_R t], \text{ and}$$

$$R_t = R_o \exp[-\delta_B t].$$

We do not have space to develop all of Schneider's rationale for this very counter-intuitive conclusion. Note the following, however. First, Schneider's development is for ground combat. Second, the basis of his conclusion is the empirical evidence -- combat data. He goes on to offer explanations for this strange data, but his theorizing [Schneider, Exponential Decay of Armies in Battle, pp. 108-

126] is, unlike Lanchester, solely for the purpose of explaining what historians have observed in practice. Third, it should be remembered that the firing side is represented by the attrition coefficient, δ, that treating the coefficient as a constant is only an approximation since the firing side's fire will diminish as it suffers loss, and that the better trained, motivated, and more numerous force will have the bigger attrition coefficient. We may summarize by saying the exponential law asserts that losses to side R at any time during the battle will be directly proportional to the fire effectiveness of side B and to the number of R remaining at that time.

D. THE OPERATIONAL ART CONNECTION

This chapter is about combat rather than operations, but before concluding passing mention should be made of another application of the exponential law. In a campaign of many weeks, losses from sickness have frequently exceeded losses from enemy action. Examples of this are the French losses in Napoleon's invasion of Russia and march to Moscow in 1812, and the US and Japanese losses in the campaign for Guadalcanal from August 1942 to January 1943. In these instances the form of the loss equations is again exponential, but the coefficients will be the coefficients representing the rate of incidence of sickness of one's own forces, and similarly for the breakdown rate of tanks, aircraft, and other vehicles.

E. THE COMMAND AND CONTROL CONNECTION

The fundamental difference between battles following the square law and those following the exponential law is the degree of control maintained by the commander over the situation. The closer command comes to bringing all its forces into action

without massing them so that they are easily targeted, and the closer it comes to the ideal distribution of fire so that each shooter aims at a different live and threatening target, the closer it comes to square law performance. According to Schneider, "In land warfare Lanchester's square law is not the reality, it is the ideal; but an ideal that must always be striven for ... [which] is, at the heart, the spark of military genius" [Schneider, Exponential Decay of Armies in Battle, pg. 57].

To the extent that a command and control system enables the commander to control the actions of his forces in combat and achieve square law effects, the system may be seen as a force multiplier. Where both forces have efficient command and control, the square law favors the side with superior numbers. Where both have inferior command and control, the linear law favors the force with better individual performance.

F. LIMITATIONS OF ATTRITION MODELS

While the attrition based models discussed provide insight into the effects of men in battle upon force strength they provide less insight into the actual processes of combat and the effects of combat upon those involved. The ability to achieve the square law effects is limited by terrain, in the case of land warfare, and by the commander's ability to maintain control over his engaged forces. Two of the most prominent factors affecting his ability to control his forces are friction and suppression.

Friction, as identified by Carl von Clausewitz, is the net effect of environmental conditions beyond the direct control of either force which when taken together

degrade the overall effectiveness of combat forces. One of the main sources of friction in ground combat is terrain. Schneider associates three principal effects of terrain with the failure to achieve decisive concentration (and by corollary, aimed fire effects): (1) degradation of attrition rates, due to reduced target size; (2) impedance to movement, which limits the optimum positioning of troops; and (3) hinderance to deployment, which limits the ability to bring all forces into combat [Schneider, Exponential Decay of Armies in Battle, pg. 55].

While the effects of friction may be felt without overt action by either force, suppression requires concentrated effort in order to achieve or mitigate its impact on operations. The goal of suppression is to inhibit the enemy's ability or desire to move or return fire. The effect is failure to concentrate or perform target selection and allocation, which breaks down the square law effect. According to Schneider, concentration "is the effective temporal and spatial ... projection of ... force ... at the decisive time and point" [Schneider, Exponential Decay of Armies in Battle, pg. 38]. By employing well coordinated suppressive fire, the commander attempts to inhibit the enemy's ability to reach the effective concentration point in time or space.

1. Intelligence, Deception, And Maneuver

Effective firepower requires the allocation of the proper weapon or force composition for a given objective; thus, concentration is the result of applying the right force at the right time at the right place. To reduce an opponent's ability to concentrate his combat power a commander must apply his force in such a way as to frustrate the opponent's attempts to mass his firepower at the decisive place and time. This may be done in various ways, two of which are deception and scouting.

Deception attempts to mask the position of one's forces, or confuse the enemy regarding one's intentions. The net effect is to cause doubt as to the actual decisive point. Scouting, on the other hand, attempts to locate the point at which the enemy should be struck.

Critical to massing one's forces is maneuverability. Freedom of movement on the battlefield is essential to achieving and maintaining concentration. Furthermore, denying the opponent freedom of movement is essential to achieving square law effects. The square law assumes constant and continuous attrition. This is only achieved when the enemy is fixed in place.

2. Pulsed Firepower And Surprise

The continuous nature of fire in the square law is incongruous with the nature of much of modern naval warfare. As will be shown in the next chapter, the trend toward aircraft carrier based forces and the use of stand-off missiles has led to a pulsed attrition, where the combat power of a force is delivered in discrete pulses or waves. Here the effects of combat must be measured after the delivery of each pulse rather than the continuous relative attrition modeled by Lanchester methods.

Finally, one factor not yet discussed which greatly impacts the results is surprise, especially so when the firepower arrives in pulses. While its effect on morale and troop posturing cannot be disputed, it is difficult to include it in an elementary model.

G. SUMMARY

The following points should be understood as a summary of the attrition modeling techniques developed in this chapter:

1. The model form will vary according to the physical characteristics of the battles. There is no general model, and the analyst must apply the form that fits the conditions.

2. Insight into the C2 contributions may be seen by the way combat power is increased through coordinated (square law form) versus uncoordinated activities (linear or exponential laws).

H. REVIEW QUESTIONS

1. Differentiate between the classical Lanchester square law and the Hughes' approximation to the square law. Which formula is more "technically" correct? What purpose or usefulness does the other equation provide?

2. What are the assumed conditions for the linear and square laws? What must be done if the assumptions are violated?

3. Given that an individual (blue) shooter can fire at a rate of 5 rounds per minute, each opponent (grey) provides a target area of 0.165 square feet (6 in x 4 in), and the field of fire is 30,000 sq ft (100 yds deep, 100 ft wide), calculate the individual effectiveness coefficient for the blue shooters if the field contains 50 enemy troops assuming that the enemy is providing sufficient suppressive fire to cause the shooters to only fire at random.

4. Given that each blue shooter in the above question presents a 0.33 square foot target to the opponent, and that each opponent is capable of placing his round in a 1 sq ft area at the same rate determine the single shot hit probability for the grey shooters. If the probability of a kill given a hit is 0.5 then determine the overall effectiveness coefficient for a typical grey shooter.

5. For problem 3, determine the initial blue troop level necessary to ensure a blue victory (at least one blue troop remaining) in a fight to the death. Is it reasonable to assume that blue would continue the fight under these circumstances (Why or why not)?

6. Given that blue has less than the minimum number of troops necessary as determined by problem 4, provide three measures which blue may take to increase his likelihood of a favorable outcome.

7. Assuming that blue is able to transition to aimed fire, has 100 troops remaining at the time of transition, each with the same rate of fire and probability of kill given a hit as a typical grey troop, use Hughes' approximation to determine the resulting troop strengths, given grey has only 40 troops remaining when the transition occurs and is willing to lose only 4 more men.

8. According to the linear and square laws, the effect of doubling one side's *effectiveness coefficient is to double the rate of losses incurred by the other.* Determine the effect of doubling the effectiveness coefficient on the exponential decay model. Which factor then has more significance in the final troop strength, initial troop level or the opponent's effectiveness?

9. Why should the goal of a force commander in combat be to achieve square law effects?

10. Why does it make sense to think of a command and control system as resulting in a force "diminisher" vice multiplier?

11. Discuss methods which a commander may take to limit the ability of his opponent to achieve square law effects.

12. Explain why force cohesion is important in battle. In your opinion, what was the benefit of drum and fife corps in battle.

13. Why is it important for shooters to return fire when pinned down?

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VI. NAVY BATTLE MODELING

AIM:

Review history to show that while force against force and attrition have been dominant in the nature of naval combat, its manifestation, and therefore the appropriate model of sea combat, has changed during four periods. The Lanchester (continuous fire) model has to be replaced in modern combat with a pulsed power model of naval combat. Emphasize the evolution of models into tactical decision aids.

OBJECTIVES:

* Present the cornerstones of maritime warfare

* Distinguish the great trends and constants of naval combat

* Discuss the functions (processes) of naval combat -- shooting, scouting, C2 and their antitheses

* Look at the evolution of naval combat and effect on C2 in terms of modeling of various force-on-force engagements:

** The age of the fighting sail and the smooth bore gun (continuous fire between ships)

** The age of steam and rifled gun (continuous fire between fleets)

** The age of aircraft carriers (pulsed firepower)

** The missile age

*** Review the modern naval force-on-force model in terms of missile attack and defense

* Emphasize that models of naval combat are attrition-based

** "Scouting" must be included for complete understanding of C2

* Examine the increasing role of tactical decision aids as used by the Navy

READINGS:

1. Wayne P. Hughes, <u>Fleet Tactics: Theory and Practice</u>.
2. Wayne P. Hughes, "Naval Pulsed Firepower Combat Model".
3. Frank M. Snyder, <u>Command and Control: Readings and Commentary</u>, "Session 4 - Operational Decisions: Decision Aids", pp. 45-55.

A. BACKGROUND

At this point the reader must recognize that the laws presented by Lanchester are simply tools which must be correctly chosen and applied to create a useful combat model. The limitations of the laws discussed in the previous chapter indicate that there must be other tools to simulate the environments and situations not covered by the Lanchester laws. Effective combat modeling involves more than a simple understanding of mathematical formulas and their applications. The formulas presented up to this point are a collection of some of the tools required for creating useful combat models.

By examining naval combat the reader will be able to see how some basic formulas can be applied to understand past naval warfare and to develop models for the future. In order to create useful combat models it is necessary to have a collection of tools other than just mathematical equations at your disposal. These other "tools" include such items as: understanding the historical application of force in the type of warfare being analyzed (naval warfare in this case), and an understanding of the trends and constants which recur in this environment. In his book Fleet Tactics: Theory and Practice, Capt. Hughes (USN Ret.) addresses the historical perspective of naval combat and the "tools" that a combat modeler must be familiar with in order to understand the nature of naval warfare. This chapter discusses the aspects of naval combat from Fleet Tactics which show the trend of combat analysis from the application of formulas to battles through World War II to the complexity of decision aids currently used in the Navy.

B. CORNERSTONES OF MARITIME WARFARE

In understanding the history of naval warfare Capt. Hughes outlines the five cornerstones of naval combat which must be kept in view at all times [Wayne Hughes, Fleet Tactics: Theory and Practice, Chapter 1]:

1. Men matter most;
2. Doctrine is the glue of tactics;
3. To know tactics, know technology;
4. The seat of purpose is on the land;
5. Attack effectively first.

The cornerstones of naval combat must be kept in mind to appreciate the trends and constants which have a significant effect on the history of naval combat.

C. PROCESSES OF NAVAL COMBAT

In order to put to use the trends and constants which make up naval warfare, it is necessary to understand that combat is a collection of processes which occur simultaneously. For combat on the seas the processes can be reduced to delivery of firepower, counterforce activity, scouting and antiscouting. The concerted effects of these processes are directed by the commander by a C2 process and opposed by C2 countermeasures. The result is delivered combat power.

The trends and constants of naval combat provide a basis in tactics and principles which underlie naval engagements. By studying these characteristics of combat a modeler will be able to understand the processes of naval combat. The

processes which are fundamental to naval combat are [Wayne Hughes, Fleet Tactics: Theory and Practice, pp. 145-146]:

1. Attrition. Naval combat is an attrition process which results from the effective delivery of firepower.
2. Scouting. The ability to strike effectively first is a direct result of the scouting process.
3. C2. The conversion of potential into combat power is the process of command and control.

The processes of shooting, scouting and C2 have antitheses. These are employed by a commander in the protection of his forces. The activities are designed to reduce the enemy's ability to deliver effective firepower, his scouting effectiveness and C2 ability. These functions are called counterforce, antiscouting, and C2 countermeasures (C2CM). The purpose of counterforce is to reduce the effect of enemy firepower by defensive fire, protective armor, damage control and other such means. Antiscouting uses whatever means available to disrupt enemy scouts and delay detection or tracking, in order to allow the advantage of the first strike to friendly forces. C2CM activities are those associated with disrupting the enemy's ability to decide, disseminate battlefield information, and deliver orders to his own forces.

D. GREAT TRENDS AND CONSTANTS OF NAVAL COMBAT

In order for a modeler to develop good models for predictions he must understand the trends of the environment being modeled. The trends in naval warfare must be acknowledged in any model which attempts to emulate naval

warfare to be true to the nature of combat at sea. Several of the key trends identified by Capt. Hughes which have affected the process of naval combat are [Wayne Hughes, Fleet Tactics: Theory and Practice, pg. 196]:

1. Shift of emphasis from speed of platform to speed of weapon.
2. Scouting has replaced the importance of ship maneuverability.
3. The range of weapons has increased significantly.
4. The lethality of weapons has increased significantly.
5. Counterforce (cover, deception, dispersion, etc.) has replaced the notion of a more survivable posture through armor, sheer size, better damage control, etc.
6. Not only has the function of scouting gained in importance, but the rate and range of scouting and surveillance has increased significantly.
7. To circumvent the increase in effectiveness and range of weapons, antiscouting has played a large role to keep forces undetected for as long as possible.

The constants which must be accounted for in a model must be understood and enforced in a manner similar to the trends. Several of the key constants of naval warfare are [Wayne Hughes, Fleet Tactics: Theory and Practice, pg. 197]:

1. Purpose of maneuver is to create an advantage in position relative to the enemy.
2. The ability to fire effectively first is the primary tactical goal.
3. The application of pulsed power may result in a victory for an inferior force.
4. Defense plays a smaller role in naval combat than in land combat.
5. There is never enough scouting capacity or information.

6. Commanders must be prepared to reallocate resources to improve scouting or surveillance even at the expense of firepower.

E. EVOLUTION OF NAVAL TACTICS

The history of naval combat has developed through several notable periods of evolution in both tactics employed and technology available. The periods of interest include: the age of the fighting sail and the smooth bore gun, the age of steam and rifled guns, the age of the aircraft carriers, and the missile age. By examining each of these periods the reader will gain an understanding of the utility of attrition-based models and also the limitations of applying a simple kind of an attrition model to all cases.

1. Age Of The Fighting Sail [Hughes, Fleet Tactics, Chapter 2]

The age of the fighting sail saw the earliest examples of the constants of naval combat. Among the constants identifiable during this period include: the noticeable effect of concentration of firepower, and the advantage of C2 to control and maneuver fleets effectively. Concentration of firepower was achieved in this period by two basic means. The first means of concentrating firepower was to put more guns on a ship by producing double and triple deck ships to fight in the line. A ship's gunfire could be concentrated against another, so that the conditions for the square law held vice the linear law. The second means involved the fighting line of ships which allowed a commander to bring all of his ships together to form a concerted effort in battle. But because effective range of the guns was short, duels between individual ships resulted, and so the linear law's conditions held. The

command of ships was simplified by the fighting line by placing the flagship in the middle of the line so that message flags could be quickly displayed to all the ships in the line.

2. Age Of Steam And Rifled Gun [Hughes, Fleet Tactics, Chapter 3]

The age of steam propulsion and the rifled gun was marked by technological advances in fabrication of steel and weapons. One of the biggest trends highlighting this period was the use of steel and other armor materials to build ships. The stronger, armor protected ships could take more direct hits and still be a strong adversary. In addition to being stronger the increase in maneuverability provided by steam plants allowed the commander new possibilities in formation and strategies. Ships were now free from dependence on the wind, and the tacticians of the time were in disagreement as to how best to use these ships in naval combats, some favoring their use as rams to swiftly destroy an unsuspecting line of ships.

Another extremely important trend followed in this period was a marked increase in the range and lethality of weapons brought on by rifled guns. The range of effective weapons was drastically increased from 300-500 yards to 8-10 miles. The increased range of weapons gave fleet commanders a new possibility for concentrating force. These new weapons allowed the commander to concentrate firepower of any and all of his ships against any ship in a concentrated enemy formation, and so square law conditions held between whole fleets. This concentration was brought out and enforced by the reemergence of the battle line [Wayne Hughes, Fleet Tactics: Theory and Practice, pg. 67]. Crossing the enemy's "T" was seen as the tactical goal of every fleet. The importance of being able to

quickly form a single battleline out of several columns (employed for cruising) emphasized the need for more scouting and reconnaissance information.

The wireless radio and extensive signal codes developed during this period altered the command and control aspects of naval combat. The flagship no longer had to be placed in the center of the formation and the scouting and reconnaissance ships could be placed well out of sight of the main formation yet communicate by radio.

3. Age Of Aircraft Carriers [Hughes, <u>Fleet Tactics</u>, Chapter 5]

The age of steam and the rifled gun gave way after WW I to the age of aircraft carriers. The effect that naval air power has had on naval combat in terms of trends, tactics and strategy is rivaled only by the effects the missile has had on modern naval combat scenarios. The ability to launch aircraft from carriers and attack at ranges 10 times greater than guns had decisive effects on the sea battles of WW II.

Aircraft squadrons provided the naval forces with two major improvements over the age of steam. The first improvement involved the range of scouting and reconnaissance efforts. Aircraft provided a longer range for scouting efforts which improved dramatically the chances of making the first strike. The second improvement involved the concentration of firepower an air wing in time. The result was a in "pulsed firepower" battle. In his paper "Naval Pulsed Firepower Combat Model", Capt. Hughes provides a model to reflect the outcome of these pulsed fire engagements which are a result of the aircraft carrier air wings.

This age of naval combat provides an excellent opportunity to apply attrition modeling to actual engagements observed during WW II. In Fleet Tactics, Capt. Hughes applied a simple tactical model of carrier warfare to demonstrate how the notion of attrition models and the pulsed firepower concept can be combined to model the carrier engagements in the Pacific [Wayne Hughes, Fleet Tactics: Theory and Practice, pp. 93-103]. This model fitted the historic battle outcomes and showed that the Lanchester continuous fire model was obsolete.

One of the most important of the trends observed in this period was the technological breakthroughs in sensory equipment. With the capability to conduct large air strikes hundreds of miles away from the carrier the need for longer range sensory information is obvious. In order to be victorious in a sea battle the force commander knew it was essential that he strike first. The technological revolution in radar, ESM, jamming, and air defense communications all coordinated in a combat information center (CIC) were paramount in the success the US forces had in naval battles [Wayne Hughes, Fleet Tactics: Theory and Practice, Chapter 5].

4. Age Of Missiles

The increases in range and lethality of weapons which occurred during the age of the aircraft carriers have undergone yet another transition in the current age of land and sea based missile. The trend of developing longer reaching weapons and the development of long range tactical and strategic missiles has had significant impact on the tactics considered for use in naval combat scenarios. Inclusive with the range and lethality of these new missiles are: a potential to concentrate firepower from widely separated ships and aircraft, a need for better scouting and

reconnaissance equipment and strategies -- including the roles of decreasing the enemy's ability to scout effectively, and the need for a more coordinated C2 system to deal with an environment to enhance friendly force's capabilities while stifling the enemy's ability to perform well -- C2CM. [See Wayne Hughes, Fleet Tactics: Theory and Practice, Chapter 10, for a development of a model which takes into account the current capabilities of long range missiles and the ability of forces to scout and perform C2CM functions to enhance the probabilities of a first strike.]

The age of missiles has brought about another concentration of firepower unique to nuclear missiles. The advent of multiple warhead nuclear missiles puts a high concentration of firepower on one weapon. The destructive capability of a single weapon now exceeds that of many third world fleets around the world. This concentration of firepower allows for multiple targeting of a site with only one vessel being designated as the shooter and the other vessels waiting in reserve.

F. FUNCTION OF SCOUTING

The function of scouting has been a recurring issue in naval combat from the earliest age of the sail ship to the modern age of missile warfare. The need to know not only where the enemy is and what his capabilities are have been shown to turn many battles into local victory for the inferior fleet. The importance of scouting in naval tactics provides a dilemma for the current force commander. On the one hand, scouting provides obvious benefits in the advantage given to the force which conducts the most effective scouting. On the other hand, scouting reduces the number of forces which can be drawn upon for firepower while the scouts are engaged in

scouting and reconnaissance. The tradeoff between ready firepower and forces engaged in search and tracking must be carefully weighed by the force commander (and combat modeler) to determine an optimum balance.

G. TACTICAL DECISION AIDS

With the complexities of such problems as scouting needs versus firepower reserves, and choice of weapons for specific targets in a modern conflict the need for and use of tactical decision aids has risen dramatically. The most significant origin of decision aiding began in WW II as operational analysis work was being conducted to help commanders make better tactical decisions and force employment techniques [Frank M. Snyder, Command and Control: Readings and Commentary, pg. 49]. The development of these decision aids is directly related to being able to follow the trends and constants of naval combat and the ability to apply the proper modeling parameters to the situation.

H. REVIEW QUESTIONS

1. List the five cornerstones of maritime warfare as defined by Hughes and describe how each affects command and control.

2. Describe the functions that result in delivery of combat power at sea. Contrast these with the processes involved in naval combat.

3. Describe the evolution of combat power at sea, in terms of changes in weapon range and lethality. What is the effect on choice of model of naval combat at different periods of history?

4. Assess the impact of changes in weapon delivery on the importance of the maneuverability of the platform.

5. Why is it so important in naval warfare to attack effectively first? How can this capability be maintained in peacetime by a country whose foreign policy denounces a first strike capability?

6. How have advances in communications technologies affected naval command and control?

7. Given the following:
$A_o = 12$, $a_1 = 0.5$, $a_2 = 2$, $\alpha = 2$, $\sigma_A = 0.5$
$B_o = 8$, $b_1 = 0.5$, $b_2 = 2$, $\beta = 4$, $\sigma_B = 0.5$
a) Use the Naval Pulsed Firepower Combat Model to compute the number of survivors, A_1 and B_1, for a single exchange of salvoes.
b) Side A determines that if he can cut his defensive firepower in half ($a_1 = 0.25$) he will double his offensive targeting accuracy ($\sigma_A = 1.0$). What effect will this have on A_1 and B_1 (assuming all other values remain constant)?

8. How has the development of stand-off missiles impacted the development of naval tactics? How does this affect the modeler and the modeling process?

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VII. NON-ATTRITION BASED MODELS

AIM:

Introduce the students to the idea that strict attrition models are not adequate in explaining the outcomes of battles. Explain how an advantageous position and maneuverability play important roles in determining the outcome of a battle in addition to the commanders' interpretation of the situation. Discuss the idea of break points and examine their use in current modeling practices. Examine some of the non-attrition modeling techniques in use.

OBJECTIVES:

* Present idea of mission accomplishment being measured in terms other than attrition, such as domination of the enemy (or control of the situation to one's own ends)

* Examine the role of suppression as a measure of dominance

* Discuss McQuie's article on break points
  ** Introduce breakpoint phenomenon
  ** How break points are established
  ** Examine the trends of dominance of maneuver over attrition

** Discuss the problem of battlefield impressions vice measuring actual losses during combat

** Emphasize that a typical engagement results in a withdrawal of forces vice a fight to the death

* Discuss methods of estimating combat potential and power

** Use of fire power indices

*** The basic form of the relationships and the applications

*** The limitations of fire power indices

** The QJM approach to nonattrition models

*** The basic form of the relationship and the applications

*** The limitations of QJM

**** The dimensional incompatibility of model

**** Power distribution and tactics

* Present a model of nuclear arms race as an example of graphical modeling techniques

** The application of the model

** The limitations of model

* Discuss the Soviet Correlation of Forces and Means (COFM) model as an extreme use of decision aids using nonattrition models

** The basic form of model

** The limitation of the model

* Review application of models to the air-land battle

  ** Present modeling of techniques at different levels - unit, division/corps, theater and global

READINGS:

1. Robert McQuie, "Battle Outcomes: Casualty Rates as a Measure of Defeat".
2. T.N. Dupuy, Understanding War History and Theory of Combat, pp. 81-89.
3. T.N. Dupuy, Understanding War History and Theory of Combat, pp. 39-50.
4. Giordano and Wier, A First Course in Mathematical Modeling, pp. 4-14.

A. MISSION ACCOMPLISHMENT

At this point the reader should begin to recognize a common problem with all the attrition models looked at thus far. Typically, the final outcome was determined by a battle to the end where one side loses most or all of his forces. In reality this situation rarely happens.

In order to understand the need for non-attrition models it is necessary to look at how a commander would answer the following questions: "How many losses am I willing to suffer before conceding my aim (mission) to the enemy?", and "What other factors influence my decision to retreat or surrender?". What casualty total is sufficient to cause the commander to admit defeat? Is the number as high as 50%, or is it closer to 10%? Can this number be predicted, or is it dependent upon the commander, his mission, and the particular engagement?

What are the factors which may affect the commander's decision to admit defeat, and how can these factors be modeled for analysis? Several possibilities for these factors include: domination -- if a commander feels that he is outmatched in the battle he may retreat early; maneuver -- if one sides forces have become surrounded and are incapable of maneuvering towards their objective they may surrender; and the environment itself -- a commander whose forces are battling in an unfamiliar environment may not feel as comfortable with a high casualty rate and may retreat earlier than expected.

The purpose of this chapter is to examine some of the models and techniques for accounting for some of the other factors which strongly influence combat outcomes in the real world.

B. SUPPRESSION

In his book, Understanding War: History and Theory of Combat, Dupuy addresses the importance of suppression in determining the outcome of battles. He defined suppression as "the degradation of hostile operational capabilities through the employment of military action that has psychological and/or physical effects [which] temporarily [impair] the combat performance of enemy forces and personnel who have not themselves been killed or wounded." [Dupuy, Understanding War History and Theory of Combat, pg. 252] As discussed earlier, the use of suppression limits a force's ability to achieve the hyperbolic attrition effects predicted by Lanchester's Square Law.

The effects of suppression were readily addressed by Marshall [Schneider, "The Exponential Decay of Armies in Battle", pg. 104] when he observed that, under the influence of enemy fire, soldiers would neglect the training and doctrine which was taught to them, calling for return of fire, to force the enemy to also go to ground. Schneider's account of the Battle of Gettysburg [Schneider, "The Exponential Decay of Armies in Battle", pg. 97] graphically depicts the effect of terror, induced by suppression, on battlefield discipline. According to Schneider many of the weapons recovered after the battle showed multiple loads, to the point of becoming a

potential pipebomb, and improperly loaded weapons, essentially useless. Here the effect of suppression effectively removed many soldiers from the battle.

Dupuy goes on to say that the amount of suppression generated is a function of the explosive power of the munitions employed, the number of rounds fired, and the rate at which the fire is delivered. Additionally, the period of time that the suppressive fire is delivered will impact upon its effectiveness: the longer the fire is delivered the greater the cumulative effect.

Dupuy notes that the effects of suppressive fire are blatantly left out of both wargaming and field exercise. However, he contends that it is essential that U.S. personnel be exposed to the reality of suppression and its impact on the battlefield.

Thus, while the effects of suppression are difficult to quantify, they can provide a means of measuring the ability of a commander to control his forces, and therefore, become a surrogate for dominance. Marshall's analysis revealed that forces held down by suppressive fire for just a couple of days became morally broken, and attempts to continue the engagement were futile [Schneider, "The Exponential Decay of Armies in Battle", pg. 104]. Thus by employing suppression a force could dominate the battlefield and frustrate the enemy's objective.

C. BREAKPOINTS

Robert McQuie's article, "Battle Outcomes: Casualty Rates As a Measure of Defeat" [ARMY, Nov 1987] examines the relationship between casualty rates in modern warfare and conflicts and battle outcomes. McQuie refers to the moment when a force commander accepts that the battle is lost as the breakpoint. In his

analysis of data accumulated by the Historical Evaluation and Research Organization (HERO), McQuie attempted to find a cause-and-effect relationship for battle outcomes.

McQuie found that on the average, defenders were willing to accept a casualty ratio with respect to initial force strength that was twice as great as an attacker's before admitting defeat. Nonetheless, he found that the median casualty levels for defenders and attackers were only eight and four percent, respectively, far less than the levels normally used for combat simulations to determine breakpoints. Exchanges ratios experienced prior to breakpoints followed the same general pattern: defenders were willing to accept losses at a rate approximately two and a half times as great as attackers.

But McQuie also concluded that neither the number of casualties experienced in battle nor the rate at which they were experienced was a driving factor in the outcome of the battle. According to McQuie, more significant to the outcome of the battles were the ability of the enemy to maneuver, the withdrawal of adjacent friendly forces and a commander's perception of near-term developments. These three factors may have a high degree of correlation, in that as a commander recognizes the ability of the enemy to envelop his forces or his inability to effectively position his forces he may sense the futility of continuing the exchange. This is compatible with Marshall's finding that once the thrust of an attack is broken and the attackers are forced to go to the ground it is very unlikely that the impetus can be restored [Schneider, "The Exponential Decay of Armies in Battle", pp. 104-105].

Thus, McQuie holds that commanders seldom commit their forces to a suicidal situation.

As pointed out by Morse and Kimball, the data available to the commander is often tainted (dirty). It may reflect inaccuracies induced by the heat of battle and overestimation of both casualties sustained by friendly forces and casualties inflicted upon the enemy. Regardless of the source of the inaccuracies, the perception in the mind of the decision maker is the basis of the decision and causes him to withdraw from a battle he can win or continue when the battle is beyond redemption. McQuie holds that, in battle, commanders are "prudent and cautious" with respect to continuing an engagement which appears to be unwinnable. Thus, misperceptions may contribute to acceptance of defeat and lead to false conclusions as to the importance of casualties in determining battle outcomes.

McQuie concludes with the observation that most battles are decided by factors other than casualties. Further, he found that the majority of engagements were terminated with less than a ten percent casualty level. Clearly, except in extreme cases, a fight to the death is atypical for land combat.

D. METHODS OF ESTIMATING COMBAT POTENTIAL

1. Firepower Index

A simple non-attrition modeling technique employs the use of firepower indices. The purpose of this technique is to aggregate a set of heterogenous elements of force into a single number representing the combat power of the forces. The model assigns a unit value to the weapon with the lowest kill potential (such as a

rifle) and scales the values for the other weapons relative to the lowest valued weapon. The individual weapon index is then multiplied by the number of weapons of that type in the force. The sum of the values are compared for each side and the highest scoring side is assumed to have the greater combat power. The firepower indexes assigned are generally determined on an historical basis, by examining the effects of the various weapons relative to other weapons over numerous battles.

The following table is an example of a firepower index model:

FORCE TYPE	UNIT VALUE	NUMBER OF UNITS	INDEX
Infantry	01	200	200
Tanks	20	20	400
APC's	10	10	100
Artillary	15	20	300

TOTAL: 1000

Although this is a better model than just counting the number of forces on each side, this model suffers from several serious drawbacks. The firepower indices are static values which do not take into account such factors as effectiveness in different terrain or environments, mobility, and offensive versus defensive uses. Another problem is that the indices are assumed to be linear -- the sum value of 1 tank + 1 tank = 2 tanks. This discounts the additive firepower effect of multiple units and the psychological value of advancing with large divisions vice a few tanks. This linearity also assumes that 100 men are 100 times as effective as a single man,

neglecting the problems associated with controlling and advancing the much larger group.

The model also suffers from synergism in that the sum of artillary, tanks, infantry, etc., is more than just the values assigned to the organic units. This is a static model which is only effective in comparing the potential of two sides. This model should not be used to describe combat power, or to estimate battle outcomes or the effect of combat force.

2. Quantitative Judgement Model (QJM)

In the early 1800's the works of Carl Von Clausewitz implied a Law of Numbers that would model military conflict. This work (On War) was seen by Trevor Dupuy (Col. USA, Ret.) to correspond to his Quantitative Judgement Model (QJM). The QJM was developed in the 1950's to account for a number of factors which influence the outcome of battle but were not accounted for in the attrition models presented earlier.

In his recent book, Understanding War: History and Theory of Combat, Dupuy derives a combat power formula based on the Law of Numbers of Clausewitz. The Law of Numbers related combat power (P) to the number of troops available (N), a term representing the variable factors affecting the force (V), and a value assigned to the fighting quality of the troops (Q) by the simple relationship: $P = N \times V \times Q$. The QJM combat power formula may be obtained by a three step process as outlined by Dupuy [Dupuy, Understanding War: History and Theory of Combat, pp. 81-89]:

1. Replace the number of troops (N) with force strength (S).

2. Quantify and define the variable factors (V) which influence the circumstances of combat.

3. Replace the troop quality factor (Q) with a relative Combat Effectiveness Value (CEV).

The QJM model replaces the force number term with a force manpower strength term to account for the lethality and effectiveness of all weapons in the force. The force strength term developed in the QJM is based on historical data and empirical results to normalize the value over the course of history to obtain comparative values. Force strength corresponds to combat potential. The QJM model has determined a finite number of variables affecting the circumstances of combat, which are classified as either environmental (terrain, weather, etc.), or operational (posture, mobility, etc.). An historical analysis was performed by Dupuy to assign to each factor a value based on its importance in combat and its relative impact on effectiveness. Finally, the CEV is a ratio of predicted outcomes measured for forces in combat against the actual outcomes and is a substitute for the Clausewitzian term (Q) in that it is a measure of relative effectiveness of one side's force against the other due to leadership, training, etc.

The limitations of the QJM lie in the historical approach taken to obtain the values of (S) and (CEV). This model works well in predicting the outcomes of historical combats. It has unknown predictive power for future combat scenarios. For example, it is challenging to obtain a good input for CEV. Where no data was obtainable or it was unmeasurable, such as for leadership, the values for opposing

sides were assumed to be equal. The drawback is, of course, shared by all attempts to analyze future scenarios.

Another significant drawback is that this model considers only those static factors which affect combat and does not account for the dynamics of combat such as tactics on the battlefield, or the effects of maneuver and supression. This model does not solve the problem of distributing force over a battlefield to obtain the best use of combat power.

E. GRAPHICAL MODELING TECHNIQUES

Students are first exposed to the use of graphs when learning to analyze simple linear equations. Later this technique is applied to more complicated systems of linear equations. In their book, A First Course in Mathematical Modeling, Giordano and Weir introduce this technique for modeling more complex relationships.

The use of graphs to analyze complex issues require that the issues be reduced to the relationship between a single independent variable and a dependent variable. In their analysis of the nuclear arms race between the U.S. and the Soviet Union, Giordano and Weir limited the variables to the number of missiles or warheads possessed by either country. To model the close interrelation between the two force structures, the graphs of each country's projected missile requirements to satisfy their strategies were overlaid. The result is a method of determining the effect of changes to one country's strategy on the number of weapons required by the other.

The limitation of this method is analogous to the limitation of the graphical method of solving simultanious linear equations -- the results are very subjective. This is especially true with the nuclear arms model presented. The actual number of missiles required to satisfy the friendly strategy of each country in the model is not explicitly determined. Nor is the survivability index which determines the actual slope of the curves used to depict the number of missiles or warheads posessed. The models presented by Giordano and Weir provide no scale to measure the number of missiles necessary to achieve stability. Thus the model is beneficial only in providing a general estimate of the effects (trends) caused by changes to either county's nuclear strategy.

The model's weakness is also its strength: it provides a quick assessment of the likely outcome of strategy or policy changes. Similar models can be generated for other complex military problems. The key is to find the critical relationship governing the problem and establish the general rules that bounds the relationship in the given environment.

F. SOVIET CORRELATION OF FORCES AND MEANS (COFM)

The Soviet military has always considered it important to study history to prepare themselves for war. The result of years of operations research in military history is the Soviet Correlation of Forces and Means (COFM) model currently in use in Soviet military doctrine. An article in the Soviet Military Encyclopedia (1979) emphasizes that COFM is an operational, tactical, and strategic model used at all echelons of the soviet military [Dupuy, Understanding War: History and Theory of

Combat, pp. 39-50]. The aim of COFM is to predict the fighting power of both sides, based on a correlation of the forces available to each side and the means required to achieve stated objectives, in order to predetermine the probable victor.

According to Soviet doctrine, a COFM margin is determined at all levels of operation and along all fronts of a battle prior to any action occurring. As a battle progresses the model is frequently updated and if an insufficient margin is determined to exist at any location then forces are shifted appropriately to enhance the margin to ensure victory while still maintaining sufficiency at all other locations.

The COFM model also takes into account variables such as: training, experience of command, motivation, reconnaissance capabilities, etc., which are related on both sides as a numerical value, or simply as "superior" or "inferior". As with QJM, these values are difficult to obtain a priori.

The limitation of this model lies in the strict adherence to the margin of superiority at all fronts. When the margin drops below a predetermined value, doctrine says that action must be taken to enhance the margin or else the mission will not be successful. With so heavy a reliance on the statistical nature of combat prior to an engagement, the COFM model does not recognize the ability of an outnumbered unit to excel in the face of battle and overcome the odds to win the battle. The uncertainty associated with combat is not recognized as being sufficient to turn a losing margin into a victorious engagement.

G. REVIEW QUESTIONS

1. List in order of importance three factors which affect a commander's decision to retreat in battle.

2. Why is it difficult for the effects of suppression to be quantified using current modeling techniques? Why is suppression of concern to commanders on the battlefield if the results are not readily measurable?

3. Historically, what percentage of losses is a commander likely to accept before retreating or surrendering? How can this percentage of losses be useful in the attrition models studied so far?

4. How can the use of firepower indices be used to evaluate what we defined in the theory of combat as combat potential? Which of the two potentials does it most likely measure?

5. What are the limitations of the firepower index modeling technique? Are these limitations serious?

6. How does the Quantitative Judgement Model (QJM) alleviate some of the problems with the firepower index model?

7. If graphical models described by Weir provide no quantitative results, then what value is there in applying his techniques? Evaluate the usefulness of graphical techniques with regard to good model characteristics given in Chapter III of the text?

8. Given your understanding of the usefulness and practicality of combat modeling, analyze the Soviet use of the COFM technique with respect to: decision making, reliability, accuracy, etc.

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VIII. CURRENT MODELS/SIMULATIONS/WARGAMES

AIM:

Introduce the student to the models, simulation, and wargames that are currently in use by the various services. Provide basic information about the models and explain how the models have been used to make C2 decisions (as decision aids).

OBJECTIVES:

* Have an understanding of the contents, purpose and use of the following military combat models, simulations and wargames:
    ** JANUS
    ** RESA
    ** CFAW

* Understand the principles of Chaos Theory

* Introduction to examples of Decision Support Systems and Tactical Decision Aids

READNGS:

1. Hughes, W. P., and J. A. Larson, "The Falklands Wargame", Appendix G.

2. Artigiani, and Gaffney, "Chaos and Command: Contemporary Science and Leadership in the Nelson Style".

3. Moughon, J.C., *A Decision Aid Model For A Maneuver Force Commander That Incorporates The Quantified Judgement Model*, Master's Thesis, Naval Postgraduate School, Monterey California, March 1989.

4. Gaver, D.P., "Naval Tactical Decisions Under Uncertainty: Some Case Studies," *Naval Research Reviews*.

A. JANUS(T)

Janus(T) is a high resolution combat simulation developed by the US Army Training and Doctrine Command to support the analysis of hardware system development efforts, employment methodology, and tactics. Additionally, the model is used to support troop training. The model functions as a Cost and Operational Effectiveness Analysis tool, one of the categories of model uses listed in Military Modeling [Hughes, Military Modeling, pp. 225-226].

The Janus(T) model employs discrete event simulation to represent the exchange of combat power between two opposing forces. Probability techniques are used to determine the combat outcomes. It models individual combat elements vice aggregated units. This allows for the assessment of the impact of a single weapon platform on the operational effectiveness of a force in combat, as well as the interaction of several weapons systems employed within a given theater.

The model is highly hardware and software intensive. The system documentation identifies a requirement for at least a Micro-VAX II minicomputer with a variety of peripherals and 85,000 lines of Fortran code, in addition to various utility and database handling routines.

B. INTERIM BATTLE GROUP TACTICAL TRAINER (RESA)

The Interim Battle Group Tactical Trainer (IBGTT), also known as the RESA model at the Naval Postgraduate School, provides an opportunity to train participants on the importance of command and control in naval operations. The model uses discrete event simulation to war game two opposing naval battle group

forces. A controller position oversees the game and may play the role of the orange force commander.

Each force has several consoles, both geographic and alphanumeric, which allow interaction with the system database and controller. Each position is provided intelligence information from the system database. Additional information may be gained by the proper use of organic surveillance systems and communications with other players. Failure to pass information between players will result in an incomplete picture of the battle situation and complicate attempts to properly control forces.

The model simulates the operations of opposing naval battle units, simulating the actions of aircraft and ships based upon inputs from participants. Command of some individual units, such as aircraft or launch facilities, are subject to the real time constraints of logistics requirements (e.g., refueling, etc.). These and other factors complicate the decision making process. On the whole RESA, or IBGTT, is effective and offers the trainees an opportunity to make command decisions in an atmosphere of stress and limited information.

C. CONTINGENCY FORCE ANALYSIS WARGAME (CFAW)

The Contingency Force Analysis Wargame (CFAW) described in the U.S. Army Concepts Analysis Agency document, "The Falklands Wargame", is a force-on-force, attrition based model which can be used by the Army Concepts Analysis Agency to evaluate the reasonableness of operation and contingency plans for joint forces at the theater level. The model supports testing of plans to meet

hypothesized scenarios, ranging over various terrain areas specified by the players.

The CFAW models the interaction of a variety of combat and combat support functions ranging from intelligence and logistics to ground and air combat. The combat potential of each opponent is generated from a database built by the players at the initiation of the game. Characteristics of each weapon system, to include probability of target acquisition and kill and target value, are provided by the players and the model uses this information to generate combat outcomes in company, battalion, or brigade size units at discrete intervals. Resulting force strengths are compared to preset percentage levels to determine the net posture of the two opponents. Should a unit strength fall below a predetermined value (e.g., 25%) relative to its initial level, it is automatically removed from further play.

The model does not make any command and control decisions. While this may appear to be a limitation of the model, it requires the players to recognize critical decision points and take action to redirect their forces. Since the model has the capability to be replayed from any point, the effects of different decisions can be played and the outcomes compared. However, the model is highly probabilistic and a given decision may not result in the same outcome each time the model is played.

D. CHAOS THEORY

Chaos theory is one of the latest theories being applied to combat analysis by military analysts. In their paper "Chaos And Command: Contemporary Science and Leadership in the Nelson Style", Artigiani and Gaffney examine the highly successful leadership style of the English Admiral Horatio Nelson within the context of chaos

theory. The paper examines how a leader can instill a common idea of how a battle should be fought and then gives his subordinate commanders sweeping authority to exercise their initiative as they see fit to accomplish the objectives of the battle. This "chaotic" style of leadership proved to be very successful for Admiral Nelson and his "band of brothers" in his various battles at sea, and is an excellent example of how the chaos theory model can be applied to think about combat.

E. DECISION AIDS

While decision aids have been used for many years to support tactical decision making, the complexity of the models used has evolved considerably from the early implementation of the maneuvering board aboard naval vessels. The advent of microcomputers and database management systems has led to the development of computer-based decision support systems to enable commanders to assess large volumes of information and make better decisions.

In his thesis, "A Decision Model for a Maneuver Force Commander That Incorporates the Quantified Judgment Model", James Coleman Moughon developed a methodology for using the U.S. Army's force readiness assessment tool, Unit Status Report (USR), to generate input values into Dupuy's Quantified Judgment Model. Moughon's effort included generating acceptable opposing force compositions, using linear programming techniques, which were subsequently input to the Janus model. The opposing forces where gamed to determine the force ratio at which the battle would turn in favor of one or the other force. By using the USR data for given units, the breakpoint force ratios predicted by Janus, and Moughon's decision tool,

a commander may be able to better predict the outcome of a battle, and thus assess the likelihood of achieving his objective. However, the breakpoint values are highly dependent upon actual force structuring and scenario construction.

Several personnel at the Naval Postgraduate School have developed decision aids as part of their individual work efforts. Professor D.P. Gaver describes three of them in his article on decision aids. In particular, these apply probability and statistical methods to assess such decisions as target selection, ranging, and radar employment.

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IX. COMMAND AND CONTROL SUMMARY REMARKS

AIM:

Relate the concepts presented to the role of command and control. Ensure the student recognizes the importance of combat modeling techniques and analysis of results in the accomplishment of combat missions and objectives. Relate the course in combat modeling to future courses to be taken in the Joint Command, Control and Communications Curriculum.

OBJECTIVES:

* Relate command and control to a decision process
* Discuss the commander's distribution of combat power spatially, temporally, and functionally
* Understand the application of combat modeling to the goals of combat

A. ROLE OF COMMAND AND CONTROL

The purpose of this course has been to give the student a perspective of combat models based on a theory of combat and a set of definitions for command and control. At this point the concepts must be tied together so that the students of command and control, for whom this text was prepared, understand the importance of the role of combat modeling with respect to other courses in a command and control curriculum.

No matter what definitions are used to discuss command and control, the underlying concept is that a command and control system is an extension of a commander's decision process by means of equipment, procedures, etc. Recall that in Chapter II "command" is a function which deals with organization, motivation, decision, and execution. "Command and control" is the process by which the commander makes decisions in order to perform his functions.

B. DISTRIBUTION OF COMBAT POWER

The final conclusion from Chapter II was that the commander's actions create combat power by activating combat potential. The purpose of the command and control process can be expressed as the commander's ability to operationally distribute his combat power spatially, temporally, and functionally in order to accomplish his mission. An effective command and control process results in the proper allocation of combat potential to generate the combat power which achieves the objectives or aims of the unit.

The role of combat models is to help the commander examine the situation before him to help him distribute the available forces in his command. Neither a model or anyone on the commander's *staff can replace* the commander's intuition or estimate of the situation in the face of combat or ignore the importance of this estimate in historical conflicts. But a combat model as a decision aid will provide a commander with information to help him in assessing the situation, allowing him to effectively distribute his combat potential.

C. GOALS OF COMBAT

In his paper "Command and Control Within a Theory of Combat", Wayne Hughes proposed three combat goals in order of importance:

1. Achieve the assigned mission;
2. Achieve the mission at reasonable costs;
3. Recognize mission accomplishment in terms of means and ends.

The importance of combat models can be examined from the perspective of each of these goals.

In assigning a subordinate a mission or objective, the superior commander must first assess the situation and determine how many units will be required to accomplish the mission (how much force must be assigned to succeed). The superior commander may have his own intuitive feeling for the situation but he must be able to process intelligence data and other information and determine the potential required.

In contrast with the superior commander, a tactical commander executes his orders and completes his mission using a number of "tools": tactical decision aids, doctrine based upon simulation, his operation order, guidance based upon environmental factors, etc. The successful commander will not only arrive at a decision by applying the most appropriate decision aid but will also understand the derivation of the aid in order to correct for his personal assessment of the situation.

As pointed out by Robert McQuie (see Chapter VII), most battles fought in history rarely resulted in the complete destruction of the opposing force. A commander faced with achieving an objective wants to be able to determine what "costs" he will permit in attempting to complete his mission. Once again, the commander must be able to examine the situation and use some sort of guide for determining whether his assessment of losses (change in potential) is acceptable in the accomplishment of the mission. If the change is too costly he must change tactics, redistribute his potential or reassess his original estimate of losses he can afford in the accomplishment of the mission, to ensure the mission is achieved. All of the available measures rely on the commander's ability to look ahead, not so much to "predict the future" as to weigh the odds and determine the possible outcomes for various scenarios. As Damon Runyon said:

> The race is not always to the swift. The battle is not always to the strong. But that's the way to bet.

Analysis helps decide how to "place your bets."

The determination of when a mission is finished or whether or not an objective has been met depends largely on the commander's assessment of the situation. Throughout the later chapters of this text, the results of Lanchester-type attrition

models have been shown lacking in ability to account for the effects of such significant concepts of: territory gained or lost, suppression, maneuverability, domination, and surprise. It becomes apparent that the outcome of a battle often must be measured in terms other than attrition. The role of the commander is to determine the processes which will help him to achieve dominance over his enemy by effective distribution of forces spatially, temporally and functionally.

D. COMBAT ANALYSIS AND THE C3 CURRICULUM

The purpose of this course is not to generate operations analysts who are experts in creating combat models. Rather, the course is designed for students in the study of command and control to emphasize the importance of combat modeling in the command and control process, and understand what factors determine whether or not a model is adequate in different situations to help with decisions and their execution. The course emphasizes the applicability of different modeling techniques in different combat environments to generate useful decision aids for commanders.

In subsequent courses in C2 Architecture Design and C2 Systems Analysis, the student should be able to see the application of combat modeling and analysis techniques. In designing a C2 architecture the goal is to determine the needs of the commander and to design an organization which will aid him in his decision making and execution effectiveness. The proper development of an organization directly affects the commander's ability to motivate and activate his forces, in order to distribute the forces and monitor the execution of his decisions.

Systems design and analysis must be based on the effectiveness of systems to help increase the combat power of forces. Models which evaluate the usefulness and effectiveness of systems in the generation and distribution of combat power are based on the techniques presented in this text. Proper model selection and analysis for a system's design and development can save the taxpayers the cost of poor systems and prove the need for, and effectiveness of, good ones.

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Command and Control
Operations Department
Naval War College
Newport, RI 02841

12. Dr. Thomas Julian 1
Director C2 Research Program
Strategic Concepts Development Center
Ft Leley J. McNair
Washington, DC 20319-6000

13. Col. T.N. Dupuy 1
DMSI
10392 Democracy Lane
Fairfax, VA 22030

14. Robert McQuie 1
US Army Concepts Analysis Agency
8120 Woodmont Avenue
Bethesda, MD 20814-2797